THE EINSTEIN ISSUE

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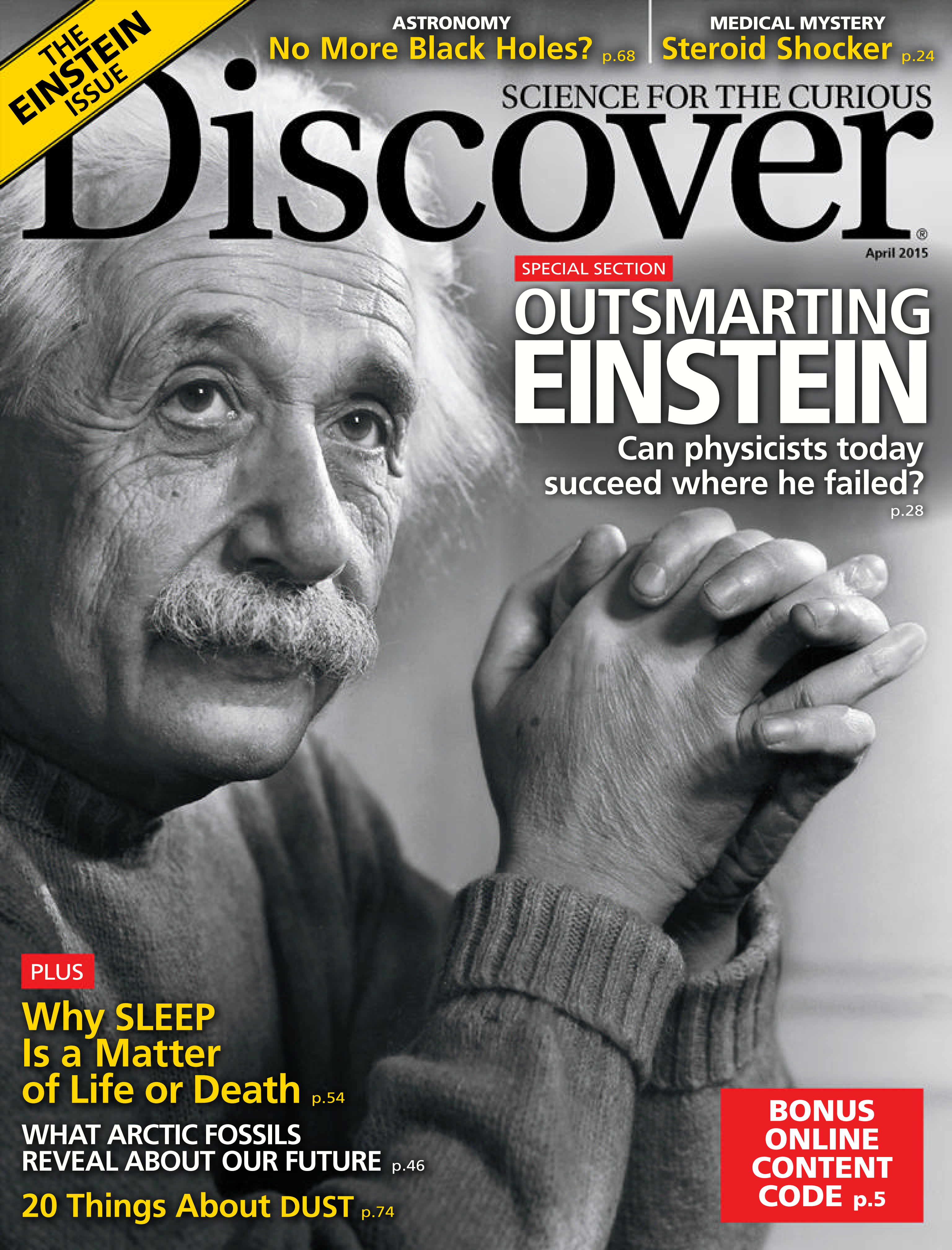
Steroid Shocker p.24

SCIENCE FOR THE CURIOUS

Discover®

April 2015



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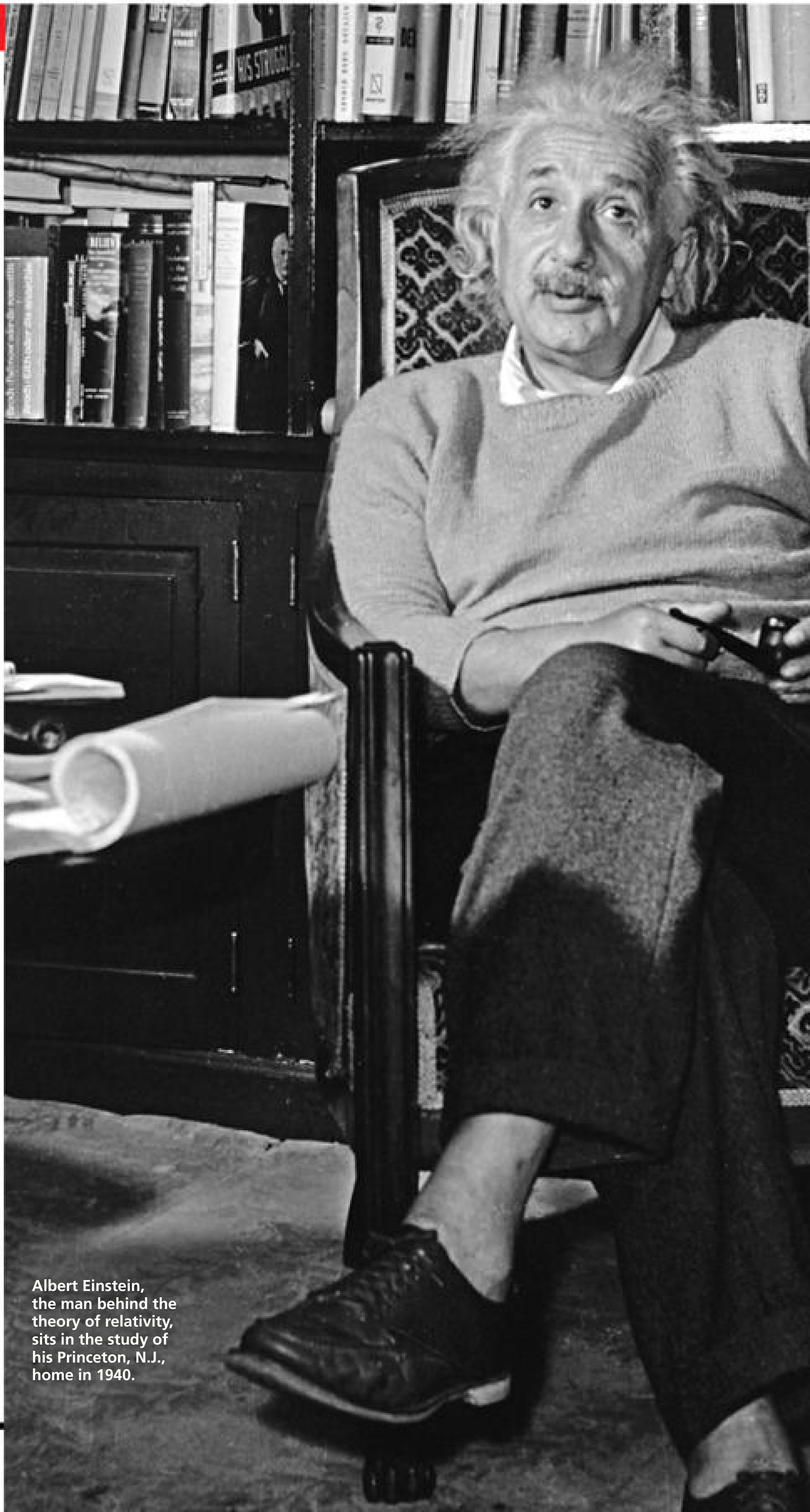

Albert Einstein, the man behind the theory of relativity, sits in the study of his Princeton, N.J., home in 1940.

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COLUMNS & DEPARTMENTS

ON THE COVER © *Yousuf Karsh.*

Editor's Note

A Hero's Journey

Meet the unsung hero of this issue. (Hint: It's not me.)

In case you couldn't tell by the cover, Albert Einstein is the hero of the issue. But if this issue were to have an *unsung* hero, it would be associate editor Bill Andrews. Over the course of several months, Bill took charge of the editorial adventure that is our special Einstein section (beginning on page 28), editing multiple stories into one seamless whole, dealing with countless pesky notes and requests from two different supervising editors and ultimately delivering a package that we trust you'll find satisfying and illuminating.

By the time you read this, Bill will be off on a new adventure — literally. We're sending him to the Norwegian archipelago of Svalbard to view a solar eclipse with several *Discover* readers. We'll have him write about his trip at DiscoverMagazine.com. Our partners at TravelQuest have two new trips coming up: a prehistoric cave art tour this fall in Spain and France, and another chance to witness a solar eclipse next spring in Bali. Visit DiscoverMagazine.com/trips-tours for more details, and perhaps the start of your own heroic journey.

NEXT ISSUE: *Meet the man who may have found the cure for addiction. See you in the May issue.*

Stephen C. George, EDITOR IN CHIEF

YOUR REPLY

Several issues ago, I asked readers to tell me about their favorite science heroes. We got many replies, but Barbara Boone's response resonated the most:

My science heroes have been some remarkable teachers. Too bad so many of the very best teachers are often so underappreciated, never knowing how dramatically they have influenced their students' entire lives.

On this page, I've given shout-outs to some former teachers, but I'd be remiss if I didn't acknowledge Mr. Moss, my freshman biology teacher, and the great Mr. Eisenhardt, who persuaded me to take calculus and — after we both realized what a big mistake *that* was — never gave up on me. Thank you, teachers everywhere.

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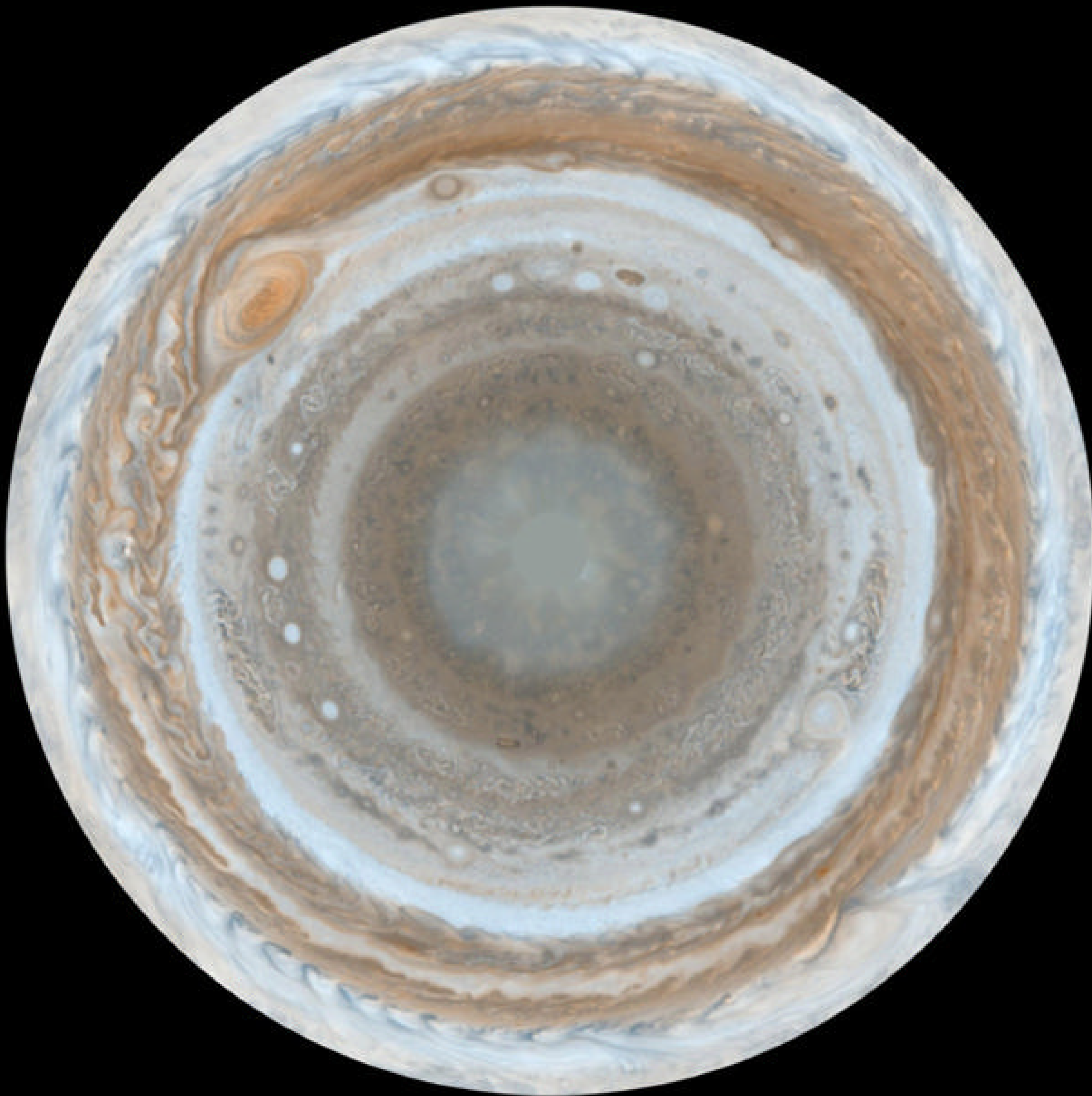
WILLIAM ZUBACK/DISCOVER

THE CRUX

The Latest Science News & Notes



COSMIC TARGET

Bull's-eye! The gas giant Jupiter looks like a target circle in this composite photo that depicts the planet's south pole. While no spacecraft has ever traveled directly under the planet, NASA's Cassini probe shot 18 photos of the pole while en route to Saturn, and the Cassini imaging team stitched them together. In reality, it's an impossible view since half the planet should always be covered in shadow. At the upper left lies the Great Red Spot, a major storm that has lasted for centuries. In addition, features as small as 75 miles across are visible throughout. — ERNIE MASTROIANNI, PHOTO BY NASA/JPL/SPACE SCIENCE INSTITUTE

Clarity for Florida's Springs

What's behind the steady algal takeover of these aquatic treasures?

BY CYNTHIA BARNETT

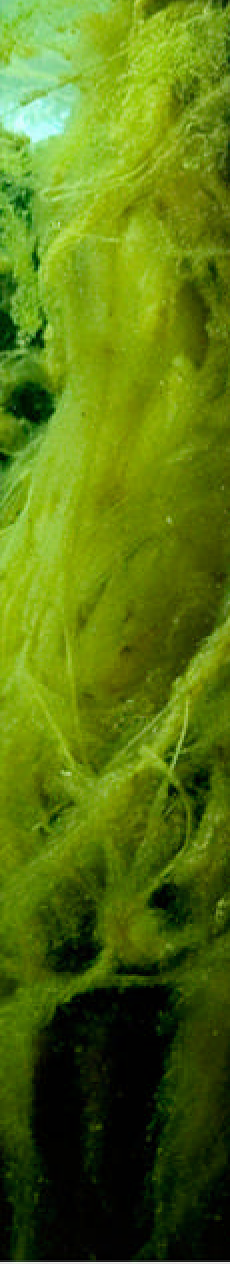
Twenty-five years ago, the striking blue waters of Florida's Peacock Springs were as clear as glass, "like a fantasy," recalls environmental scientist and cave diver Pete Butt. Snorkeling at the surface, he could see through the water to the limestone bottom and its craggy portals to one of the longest underwater cave systems in the nation.

Divers still converge on Peacock and the other springs that sparkle azure in the forests of northern and central Florida. Yet outbreaks of algae have started to cloud the crystal waters — along with the future of Florida's collection of more than 1,000 freshwater springs, one of the world's largest concentrations.

Algae clump on the surface in smelly mats, smother native aquatic vegetation with slime or grow along the bottom in hairy, green strands. "Amorphous goo," Butt calls it. "Atrocious."

Scientists have long tied the rise of algae to that of nitrate pollution from fertilizers running off farms and yards, and organic wastes from septic tanks, dairy farms and city wastewater systems. Another suspect: groundwater pumping of the Floridan Aquifer, which

In Troy Springs State Park, algae spread from the edge of Troy Springs to about 30 feet below the surface, clouding the water and smothering native vegetation.



It took just 18 months for algae to invade and choke Devil's Ear Spring.

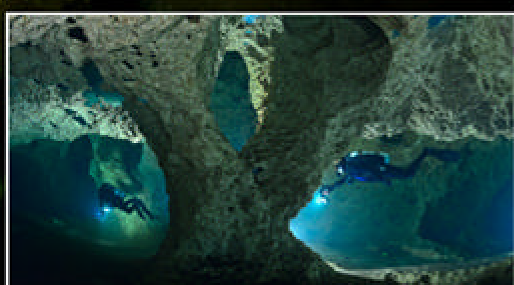
Analyzing sensor data and field measurements, Cohen and his students have found new clues for the algal abundance, such as declining concentrations of dissolved oxygen and the role of snails in keeping springs clear. One hypothesis is that as groundwater pumping depletes shallower, more oxygen-rich water, the older, oxygen-poor water flows from the springs, perhaps making them inhospitable to snails and other grazers.

Sensors in Ginnie Springs (top) and Gum Slough (above).

Farmers are working to change land-use practices.

Two state agencies are teaming up with farmers in a 185-square-mile area near Ginnie Springs to study best-management practices, such as reducing groundwater pumping and fertilizer use. Seventy percent of farmers in the area are on board. In the future, Katz says, environmental scientists hope to work with homeowners and local governments to reduce septic-tank and sewage pollution.

A new joint project of Florida's agriculture and environmental protection agencies combines spring water monitoring with land-management changes in the local watershed. Last spring, Butt, owner of Karst Environmental Services, mounted a special pump at Ginnie Springs, a popular diving and tubing spot outside the city of High Springs. The pump sends water to a nitrate sensor and a device called a sonde — French for "probe" — that measures water temperature, dissolved oxygen levels, pH and dissolved minerals. Then the data can be accessed instantly on the web.



Increased algal growth threatens attractions like Peacock Springs, whose caves are part of the longest underwater cave system in the country.

Matthew Cohen canoes Gum Slough to reach sensors that monitor water quality.

provides the majority of drinking water to the state's booming population and irrigation for most of its crops.

In recent years, though, scientists have begun to see that the causes are not entirely clear, says Matthew Cohen, a hydrologist and ecologist at the University of Florida. For example, some springs with the lowest nitrate levels, such as Alexander Springs in the Ocala National Forest, are matted with some of the worst gunk.

To identify the problems and potential solutions more precisely, Cohen and his students have spent seven years analyzing water-quality data collected through tube-shaped sensors submerged in northern Florida's rivers and springs. Last year, state environmental protection and agricultural agencies added real-time monitoring on the web, in addition to a project they started in 2013 with farmers, to try and tie specific land-use changes to water quality. For the first time, scientists will have an instant read on how springs respond to all sorts of factors, from fertilizer application to drought or heavy rainfall, says Brian Katz, a geochemist with the Florida Department of Environmental Protection. Clearer science, says Katz, "will eventually lead to clearer springs."

LARGE PHOTO: ALAN YOUNGBLOOD/OCALA STAR BANNER/LANDOV. INSET FROM TOP: MARK LONG (2); JENNY ADLER (2); BRAD MCCLENNY/GAINESVILLE SUN/LANDOV; MARK LONG. TOP RIGHT: JENNY ADLER

Finch specimens collected during the second voyage of the HMS *Beagle* in the 1830s.

Species Stuck in Neutral

Darwin's finches are icons of evolution, but did we get the story wrong?

The finches that Charles Darwin collected in the Galapagos Islands are considered textbook examples of how a single species differentiated into many to exploit different resources. Subtle changes in the size and structure of beaks among the six species of ground finches have been called "evolution caught in the act." But are they really one species, or several? In Science Smackdown, we let experts argue both sides of the question.

NO NEW SPECIES

The textbooks are wrong, says ornithologist Robert Zink of the University of Minnesota's Bell Museum of Natural History. The ground finches may seem to be different species, at least with superficial comparison, but they're stuck in what he calls Sisyphean evolution. "Species kind of get started, but … they never make it to the top of the hill," Zink says.

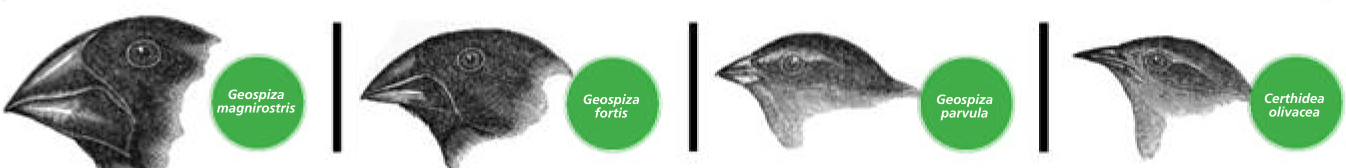
In a recent paper in *Biological Reviews*, Zink helps make the case. "None of these 'species' are distinct," he says. The various ground finches don't differ significantly in ways that usually differentiate bird species, such as plumage patterns or song. Unlike with discrete species, these features aren't stable and can vary over just a few generations, depending on weather and food availability. Sequences of their nuclear and mitochondrial DNA show little variation and none of the telltale signs that suggest distinct species.

The circumstances in the Galapagos — frequent interisland travel due to short distances between islands and interbreeding — prevent the finches from truly forming distinct species. It makes more sense to classify the birds as a single species of ground finch with ecologically driven variations, Zink says.

SPECIES, SPECIES EVERYWHERE

Princeton-based husband-and-wife evolutionary biologists Peter and Rosemary Grant disagree. They started studying finches in 1973 and have long held that ground finches represent "species before speciation is complete." (In fact, that's how they titled one of their papers.) It's natural that the nascent species would show genetic resemblance, Peter Grant says. Nonetheless, the traditional view that the ground finches make up six species holds up on the basis of breeding behavior and songs.

"It makes no sense to us as biologists studying populations in nature to combine them all into one species," says Grant. Despite rare hybridization, the finch populations remain behaviorally and morphologically distinct and, according to Grant, are on their way to becoming separate species. – GREG BREINING



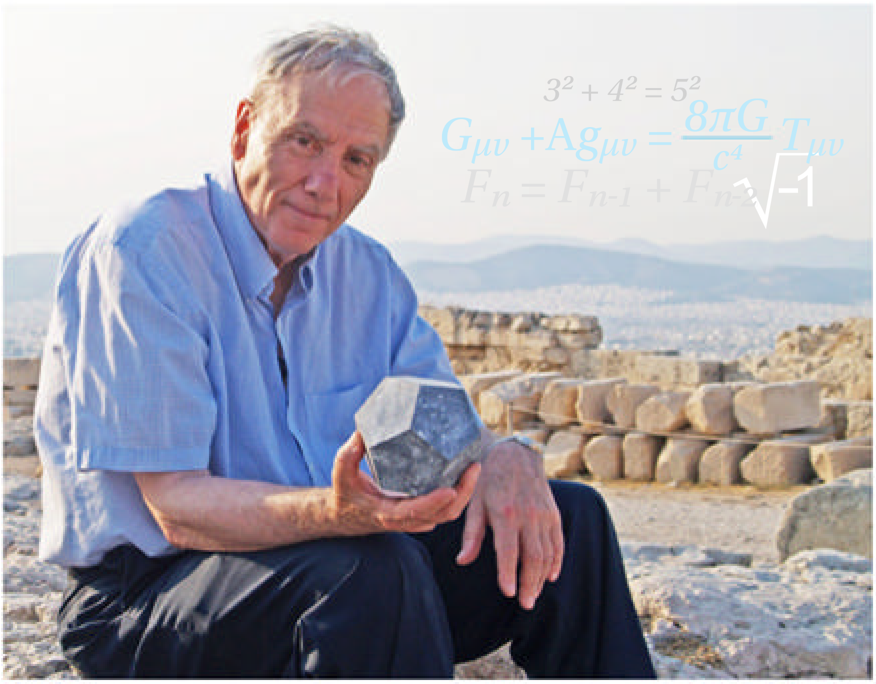
A sampling of the differences among certain Galapagos finches.

TOP: THE TRUSTEES OF THE NATURAL HISTORY MUSEUM, LONDON. BOTTOM: GRANGER, NYC

The Numbers Game

NOVA, "THE GREAT MATH MYSTERY"
9 p.m. EDT April 15, PBS (check local listings)

Math surrounds us, from satellites orbiting above us to the pattern of flower petals in your garden. But did humans invent or discover math? Astrophysicist Mario Livio, author of *Is God a Mathematician?*, hosts *Nova*'s intriguing new hourlong documentary that explores the origin of numbers and the rules that govern them. Livio chatted with *Discover* Senior Associate Editor Gemma Tarlach about how it all adds up.



WGBH

Q *You've said humans invented the concept of math but then discovered the relationships among the different concepts we invented. How is it possible to invent things and then discover pre-existing relationships between them?*

A First, I want to make clear that I'm not hedging my bets about whether math is invented or discovered and choosing something in between. The question of whether math is invented or discovered is itself misleading because it gives you the impression it has to be one or the other. Humans looked around and saw two eyes, two legs, two breasts. They had no "2" but, from what they observed, they abstracted the concept and invented the number 2 — the number itself you couldn't see in nature. In that way, we invented the concept of natural numbers. But the theorems were forced upon us: 3 squared plus 4 squared equals 5 squared. We have no choice. This was discovery.

Q *But couldn't one argue, say, the concept of "2" has always existed, and we just gave it a name?*

A It's not a name; you could call it 2, you could call it schmoo, but the fact that there is an abstract concept common to all those things, that's the thing we invented. Because natural numbers are so natural to us, you may have thought people didn't need to invent them. But look at fractions, which we abstracted from experience. You cut a loaf of bread in half and you have a half. You have to come up with the concept of "half."

Q *Does the process of invention and then discovery also apply to imaginary numbers?*

A Yes. Take the square root of negative 1. This number did not exist, even after people invented numbers by abstracting the concept of them. But people tried to solve cubic equations and, in the process of doing that, invented the square root of negative numbers. There is no number that, when you square it, gives you a negative. We invented the new concept of imaginary numbers and then discovered a whole new area of complex relationships that existed around them.

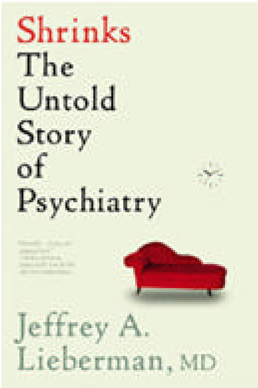
Q *Math is, pun intended, integral to our world. So why are there so many different ways to teach it?*

A The world today is not what it was 30 years ago. You want the education system to reflect changes in society. Your phone uses GPS and communicates with three or four satellites in order to determine your location. To do that, it must use Einstein's theory of special relativity and his theory of general relativity. Special relativity because the satellites are moving much faster than you are, general relativity because the satellites are much farther from Earth, with weaker gravitational pull. Clearly not everyone needs to know Einstein's theories to use the phone, but we are living in a very technologically advanced society, and math education needs to keep up. Math should be treated as part of general human culture, in the same way that we study literature and arts and history. Students should know that there are such things as the laws of nature and physics, which we believe govern every single phenomenon in the universe, even if they don't study in detail what those are.

Q *What's your favorite equation?*

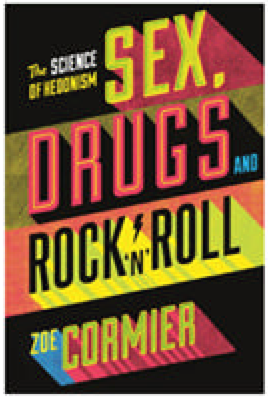
A Einstein's equation of general relativity. I know it is really a set of equations, but it can be written in concise form: It is matter and energy of the world that determines the geometry of space. Mass causes space around it to warp. Think of it as me, standing on a trampoline, causing the trampoline to dip. It tells us gravity is not some mysterious force; it's just an expression of the curvature of space.

BOOKS



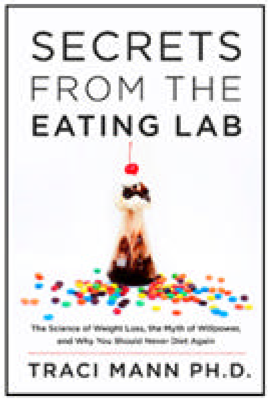
SHRINKS
By Jeffrey Lieberman

Pill pushers, head shrinks, orators of psychobabble — psychiatrists have been called many names, not all of them complimentary. Lieberman, former president of the American Psychiatric Association, confronts his field's sometimes negative image head on, acknowledging psychiatry's seedy past and the rogues and charlatans who led it astray. From squalid asylums and ice pick lobotomies to the dawn of antidepressants and MRIs, *Shrinks* details psychiatry's missteps and failures, and eventual triumphs, as Lieberman tries to shake off the debilitating stigma that clings to mental illness — and the people who treat it. —BRENDA POPPY



SEX, DRUGS AND ROCK 'N' ROLL
By Zoe Cormier

Cormier, part of the artsy collective Guerilla Science, promises stories of scientific discoveries made through tripping, rocking out or getting busy in bed. She doesn't quite deliver on that pitch, though tales of Nobel-winning work enhanced by LSD come closest. Instead, the book evolves into a tour of the science behind our baser pursuits. By turns wry and giddy, Cormier teases out our uniquely human take on hedonism with tidbits as varied as the power of our orgasms (hint: no other creature on Earth can best us) and what the discovery of a 40,000-year-old wooden flute reveals about music and our ancestors. —ELISA NECKAR



SECRETS FROM THE EATING LAB
By Traci Mann

Founder of the University of Minnesota's Health and Eating Lab, Mann puts what she calls the dieting industry's "sacred cows" on the menu in a book that's equal parts science and self-help. Diets don't work, she argues, and obesity is not deadly. After summing up decades of research on the physical and psychological factors behind eating, starving and yo-yo dieting, Mann suggests common sense strategies to achieve a healthy weight — which has more to do with your genes than your jean size — and accept your body for what it is. —GEMMA TARLACH

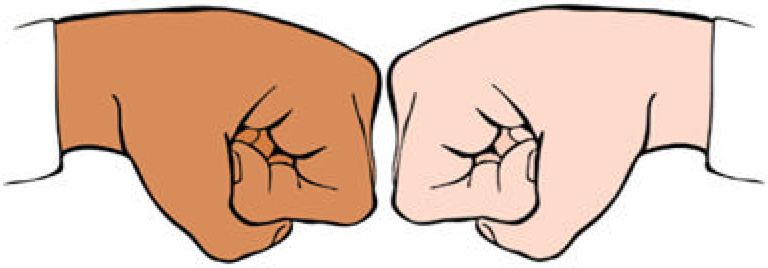
INBOX

Understanding Addiction

Our profile of neuroscientist Nora Volkow, "This Is Your Brain on Drugs," appeared in the December issue.

As a high school health teacher, I found Volkow's research on the biological basis of addiction empowering. Students should look beyond the explanations of willpower, deviant behavior or peer pressure to understand how psychoactive drugs alter brain chemistry. When students ask me, "Why do people take drugs?" I can now discuss how individuals with a low density of D2 receptors are less sensitive to dopamine, predisposing them to drug abuse and obesity. This transforms the discussion of addiction from one of willpower or immorality and places it squarely in the field of neuroscience.

Molly Sultany *Portland, OR*



GERMY GREETINGS

A fist bump might not be as professional as a handshake, but at least it's cleaner. Biologists at Wales' Aberystwyth University coated rubber gloves with nonpathogenic *E. coli*, then exchanged greetings with sterile-gloved researchers. They found that fist bumps transferred only about one-tenth of the amount of bacteria as handshakes did. Even high-fives were half as germy as a more traditional clasp. So the next time someone offers you a hand, just say, "Pound it."

—CALEB O'BRIEN

INBOX

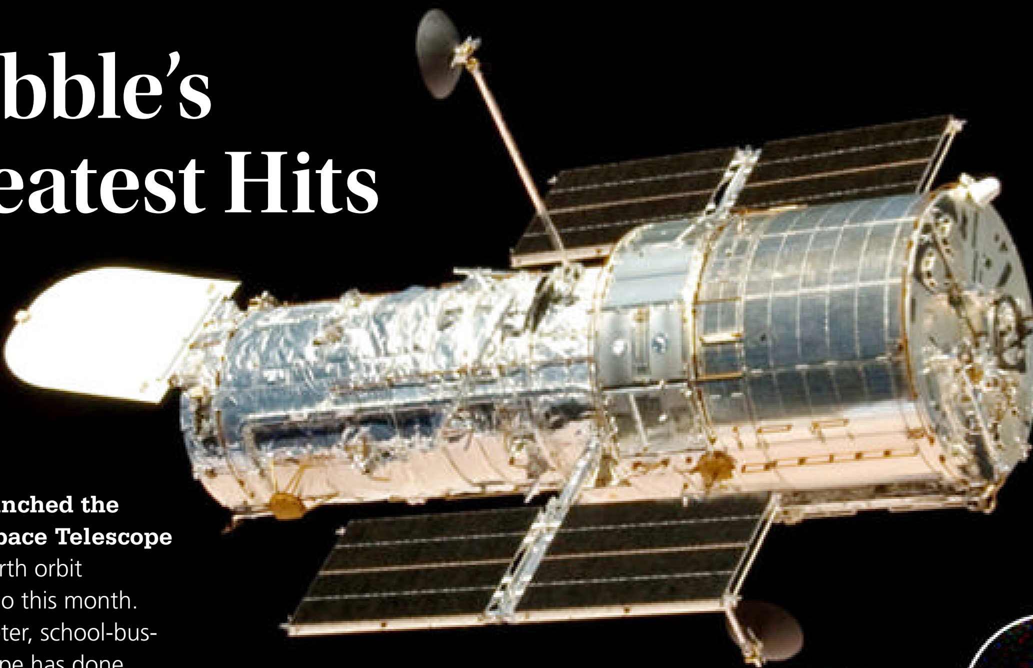
Discover-ing Science

I first, um, discovered *Discover* when I was the teacher's assistant for my high school's physics teacher. One of my projects was to go through her magazines and look for articles she could reference in her energy unit. As I made copies of possible info, I began reading little snippets of your magazine. That's when I fell in love with particle physics. Throughout middle school, it always seemed like we were exposed only to things we already knew. There was no inquisition, no discovery; we found only what we were led to. The idea that science could be so unknown and theoretical appealed to me, and I began reading nonfiction and paying attention during science class. When my teacher canceled her subscription a couple of years later, I began my own. Since then, I have been following science through your magazine and continue to feel wonder and awe at our amazing universe.

Brenna Saxton *Monroe, WA*

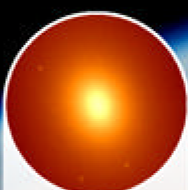
JOHN T TAKAI/SHUTTERSTOCK

Hubble's Greatest Hits



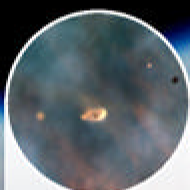
NASA launched the Hubble Space Telescope into low Earth orbit 25 years ago this month. The 2.4-meter, school-bus-size telescope has done nothing short of rewrite how we see the universe and how we understand it.

—KATHERINE KORNEI



1990
Supermassive Black Holes

Hubble images revealed that most galaxies contain supermassive black holes millions of times heavier than the sun. Astronomers are still trying to work out the full relationship between a galaxy's evolution and its black hole.

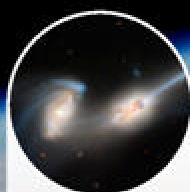


1991
Nascent Solar Systems

Data showing pancake-shaped objects within a distant cloud of gas and dust provided the first views of protoplanetary disks — the birthplace of stars and orbiting planets, including our solar system.

1992
Dark Matter

Einstein predicted that the gravity of massive bodies could alter the path of light. (For more, check out our "Outsmarting Einstein" section on page 28.) When Hubble observations showed this also occurring around galaxies too puny to warp light by themselves, astronomers realized that the galaxies must be suffused with an unseen kind of material — dark matter — that invisibly adds mass to the universe.

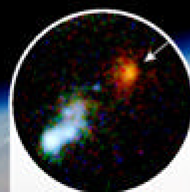


1993
Colliding Galaxies

Hubble has captured images of galaxies in midcollision, with their spectacular streams of stars, gas and dust. These crashes can trigger the birth of new stars, which may go on to form their own solar systems.

1995
The Hubble Deep Field

After pointing Hubble at a supposedly blank section of sky for more than 100 hours, astronomers discovered thousands of tiny, distant galaxies. Not only does it hint at the universe's unexpected richness, but that abundance suggests that small, irregular galaxies merge to form the larger ones more familiar in our cosmic neighborhood.



2001
Dark Energy

Hubble data on stellar explosions in distant galaxies gave astronomers their best measurement of how fast the universe is expanding. To their surprise, they learned the expansion rate is actually speeding up — some still-mysterious repulsive force, dubbed dark energy, is actively pushing the universe apart.

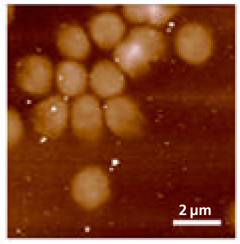
NASA/ESA/STSCI

Healing Helpers

Artificially created platelets could save lives someday.

On a war-torn street of the future, an American soldier lies sprawled, unsure if a nearby blast has harmed him. Is there internal bleeding? He carries an injector containing artificial platelets, which will augment his body's normal clotting mechanism and curtail any hemorrhaging. Yet the injection will be harmless if he has escaped injury.

"You don't want a soldier or medic to stress," says Thomas Barker, a biomedical engineer at the Georgia Institute of Technology. "'If I inject this, am I causing myself harm?' We wanted to take the decision out of the hands of the soldier."

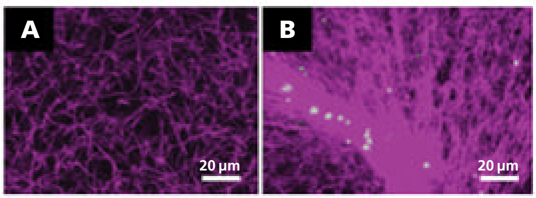


A microscopic view of the artificial PLPs that augment the body's natural clotting process.

Supported by a U.S. Department of Defense grant, the National Institutes of Health and the American Heart Association, Barker and his team have created what they call platelet-like particles, or PLPs, according to a study published in *Nature Materials*. Already, the team has successfully tested these particles in lab rats and in miniature tubes of human blood.

The not-quite-cell-size PLPs, gel-like structures consisting mainly of water, circulate innocuously, just like normal platelets. When a wound occurs and clotting begins, tailor-made antibodies on the PLPs' surface seek out and bind to fibrin, a type of protein that makes up the wound-healing mesh natural platelets fill. In effect, the artificial platelets join forces with the natural ones in making a clot. And if not needed, the PLPs are likely excreted as waste like any other small particle, Barker says.

In emergency room and surgical situations, as on the battlefield, PLPs could prevent someone from bleeding out. But they could also prove useful in cancer treatment centers, where patients frequently need platelet transfusions. Because donated platelets degrade in just five days, they are continually in short supply. Their synthetic substitutes ought to be ready for human trials in about three years, Barker estimates. — JEFF WHEELWRIGHT



A clot (A) formed with natural platelets on fibrin, shown in purple, and a denser clot (B) formed with added PLPs, shown in white.

Thomas Barker and Ashley Brown, a research scientist, examine a bacteria plate from their PLP work.

PLATELET PHOTOS: ASHLEY BROWN/GEORGIA TECH (3). BOTTOM: GARY MEEK/GEORGIA TECH

This Computer's Always in School

Thanks to the supercomputer that is our brain, we can make lightning-fast inferences and associations between images and situations. For a real computer, though, the same task is a bit harder. That kind of advanced visual processing requires significant artificial intelligence (AI) — the ability to perform humanlike cognitive tasks such as reasoning, generalizing and learning from past experience.

Yet, since summer 2013, NEIL — the Never Ending Image Learner — has been hard at work at Carnegie Mellon University analyzing and forming relationships between images from all over the Internet. The better the system gets, the closer we are to truly powerful AI and a new era of smart technology.

Made up of two computer clusters housing a total of 200 processing cores, NEIL is programmed to organize its database into three categories: objects (such as computer or Corolla), scenes (alley or church) and attributes (blue or modern).

Researchers left NEIL to itself to analyze online images, using an algorithm that allows it to build connections — the heart of its AI. Those connections include object-object relationships ("eye is part of baby"), scene-object relationships ("bus is found in bus depot"), object-attribute relationships ("pizza has round shape") and scene-attribute relationships ("alleys are narrow"). NEIL then adds these relationships to its database, giving it more data so it can become even better at finding new associations.

"Gathering visual common sense is an extremely difficult problem," says Abhinav Gupta, principal investigator on the NEIL project. "The problem is considered to be among the hardest in all of AI because the breadth and richness of common sense is enormous."

It's important to develop strategies, like NEIL's learning algorithms, that allow computers to recognize, categorize and respond to images as the machines become more incorporated into our lives, Gupta says: "Over the past decade, AI researchers have made tremendous advances in the field of computer vision. For example, object and scene recognition. NEIL is a small step toward the long-term dream of making truly intelligent machines."

While NEIL may one day learn to make new kinds of connections — and Gupta's team hopes to develop novel applications of the software — there's no real endpoint to the project. "In a manner similar to humans," Gupta says, "we expect NEIL to keep learning in a never-ending fashion." So far, NEIL has analyzed more than 10 million images and created 5,000 likely relationships between them. As some of the examples at right show, sometimes NEIL does a great job linking the concepts behind images, and sometimes … not so much. — MICHAEL FRANCO

DOES NEIL MAKE THE GRADE?

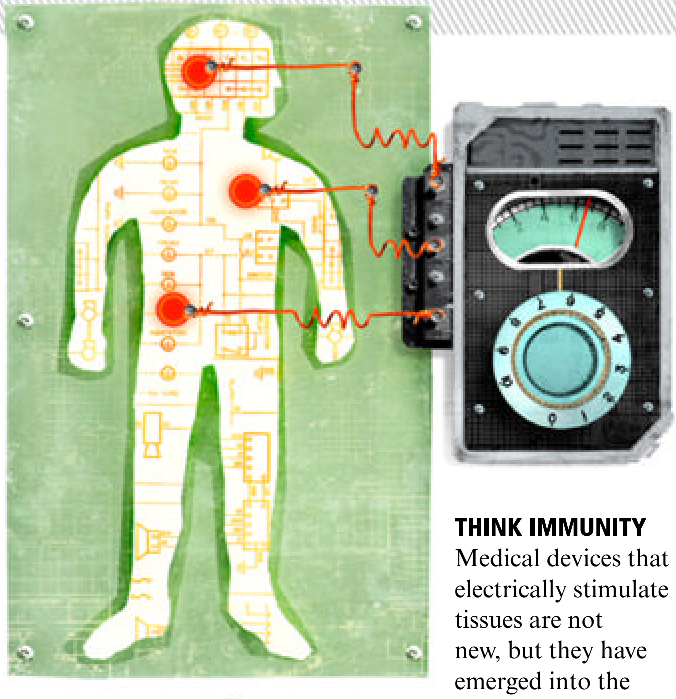
Some of the image-learning AI's greatest hits (and misses)

THINKSTOCK EXCEPT PAC-MAN BY ALISON MACKEY/DISCOVER. LEFT COLUMN: JANNIWET; SELLINGPIX; MUSTAFA ALMIR MAHMOUD; PITRIS; BOARDING1NOW; CLAUDIODIVIZIA; AAROWS; FUSE. RIGHT: STOCKBYTE; VENTDUSUD; MISS_ELLI; WILDPIXEL; ODNEOKO; SOLARSEVEN; BAHADIR-YENICERI; COSTASD68; SANSANTIE09.

Impulse Control

Tiny bioelectronic devices surgically implanted on nerves interfere with and change the body's own processes to make them function better.

BY **CAROLINE BARLOTT**



David Kessel's high blood pressure started when he was just 13 years old. His doctors gave him many tests, but they never determined the cause. By his early 20s, he was taking 17 different pills a day, yet he still had a hard time climbing a flight of stairs without getting winded. He wore a blood pressure monitor, and its reading routinely hovered dangerously high.

In summer 2005, Kessel signed up for a clinical trial in St. Louis, near his home. Surgeons working with a Minneapolis-based company called CVRx implanted an electrode the size of a half-dollar on his carotid artery. After the surgery, a battery-powered generator implanted in his chest electrically stimulated pressure sensors in the artery. Those sensors sent impulses to the brain, which, in turn, fired signals to reduce his heart rate and relax his blood vessels.

"I could actually feel my blood pressure going down," says Kessel. Nine years later, he not only can get through his days without feeling exhausted, but he can also go on long bike rides with his two daughters.

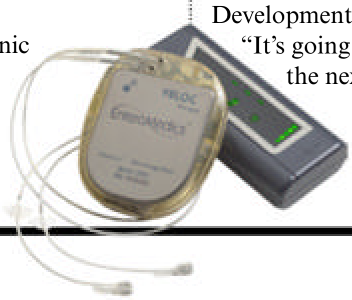
Pharmaceuticals are often a doctor's first line of defense when treating everything from infection to diabetes. But if the fledgling field of bioelectronic medicine takes off, devices like Kessel's could give doctors a whole new tool in their arsenal.

These new bioelectronic implants are designed to sit on or near nerve bundles. There, they modulate the electrical impulses that travel between our brain and our organs. These impulses regulate everything from heart function to body movement.

Disease or injury can prevent nerves from sending appropriate signals, or force them to send inappropriate ones. By reading and regulating those signals, the new devices — most are in their early stages and many have yet to be officially approved — alter how specific nerves fire, thereby modulating organ function. That, in turn, could treat ailments as diverse as sleep apnea, rheumatoid arthritis, diabetes, obesity and more.

The first of these implants have begun to reach the market. In 2014, the FDA approved implants to treat sleep apnea. This year, the agency approved a weight-control device that creates a feeling of fullness. Many companies are investing in the technology, including pharmaceutical giants such as GlaxoSmithKline, which launched a venture-capital fund that will invest $50 million into companies creating bioelectronic medicines.

"Researchers are even exploring how the technology can be used to treat cancer," says Kristoffer Famm, head of the Bioelectronics Research and Development unit at GlaxoSmithKline. "It's going to be exciting here over the next five years."



This pacemaker-like device helps control appetite.

THINK IMMUNITY

Medical devices that electrically stimulate tissues are not new, but they have emerged into the medical mainstream in recent decades. Cochlear implants help the hard of hearing by stimulating neurons in the brain's auditory cortex, while deep brain stimulation improves mobility for those with Parkinson's disease by delivering electrical pulses that inhibit abnormal nerve signals. People with paraplegia can control their bladder through sacral nerve stimulation, facilitating communication between the bladder and brain.

But these devices work crudely, and in many cases they disperse electricity to many nerve bundles instead of specific ones that control individual functions. Sometimes this results in negative side effects. For example, stimulation of the vagus nerve — a major nerve that travels from the brain to the colon, regulating everything from our hearing to our heartbeat — is a common treatment for epilepsy, but it can cause difficulty swallowing.

These devices are medically revolutionary, and they represent just a small sample of what is possible for bioelectronic medicine, says neurosurgeon Kevin Tracey, president of the Feinstein Institute at North Shore LIJ Health System in New York. In the late 1990s, Tracey discovered that stimulating the vagus nerve also

TOP: RICHARD BORGE. BOTTOM: ENTEROMEDICS

alters immune function. A company he later founded, SetPoint Medical, discovered that stimulating the nerve could stop inflammation to fight rheumatoid arthritis.

"We found that the immune system functions as an innervated organ just like the heart," says Tracey.

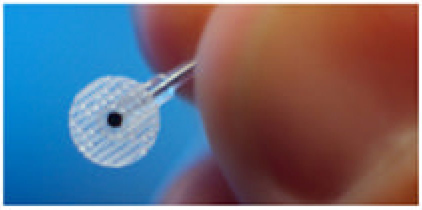
It was a game changer. Autoimmune diseases — such as rheumatoid arthritis, multiple sclerosis, inflammatory bowel disease and lupus — now could be treated electrically. SetPoint Medical went on to develop the first bioelectronic devices to treat rheumatoid arthritis. In 2012 the company announced results from the first clinical trial for European patients with rheumatoid arthritis, with eight people participating in the trial and nearly two-thirds experiencing benefits.

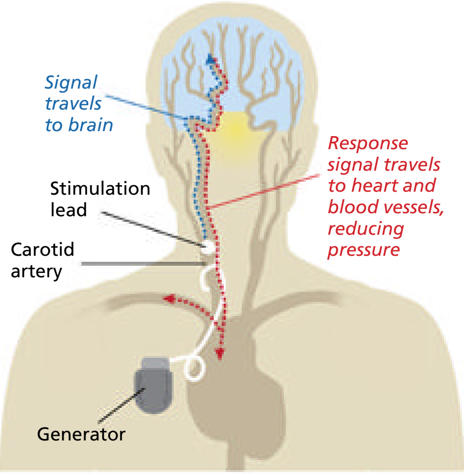
TINY AND MIGHTY

To develop new bioelectronic therapies, scientists must first map the neural circuits and determine patterns of neural firing that correspond to healthy organ function. Then they need to figure out how those patterns go wrong to cause disease. To that end, the National Institutes of Health has invested $248 million over the next six years toward mapping the detailed wiring of the nervous system.

Neurons also have characteristic patterns of electrical impulses, akin to the dots and dashes in Morse code, and neuroscientists are investigating them to determine how they malfunction to cause disease and how to restore the pattern displayed in a healthy body. Meanwhile, research on brain-machine interfaces is producing electrodes that can interact with individual neurons, giving scientists more precise control of neural circuits than ever before. And scientists are designing microchips based on brain function, to make them work more intuitively.

Engineers are also working to miniaturize bioelectronic devices, lowering the risk for patients when the devices are surgically implanted. When surgeons wrapped Kessel's half-dollar-size electrode around the carotid sinus, for example, they had to dissect around many nerves — a procedure that carried a large risk of nerve damage.





CVRx's latest technology can help the body regulate blood flow. The generator (left, bottom), implanted beneath the collarbone, sends signals through the lead (left, top) to the brain.

To keep patients safer, biomedical engineer Kip Ludwig, who worked at CVRx years after the start of Kessel's trial, and his colleagues spent several months using computer models to design a far smaller device. They tested prototypes in laboratory animals and worked with vascular surgeons to see how the design would impact the surgical procedure and to better understand the physiology of the process. The company also performed "benchtop" simulations on a prototype that mimicked worst-case scenarios — such as bending and stretching of the device — to ensure it would stand up to normal wear and tear over a lifetime of use and wouldn't degrade and release harmful substances.

The result was a durable electrode 8 millimeters across, about the diameter of a pencil eraser, that surgeons can implant on the carotid artery with just a tiny incision, and a longer-lasting battery that minimizes replacement operations. Another CVRx team shrank the battery-powered generator by about half to roughly the size of a USB thumb drive. In August 2013, Kessel had the newest version of the device implanted, and it works as well as the original.

The goal of streamlining useful but clunky bioelectronics actually drives the whole industry right now, says Ludwig, who has since left CVRx and is now the program director for neural engineering at the National Institutes of Health, where he allocates money to other bioelectronics researchers to develop smaller, more effective devices.

Second Sight, a bioelectronics company in Sylmar, Calif., uses electrodes to stimulate the retina, and the devices have partially restored sight in nearly 100 patients. New cochlear implants now allow deaf people to have phone conversations. Last year, a Columbus, Ohio-based team implanted an electrode in a paralyzed man's brain and connected it to a sleeve on his wrist, effectively allowing the man to move his hand with only his thoughts.

Bioelectronics could one day even help people with paraplegia walk. University of Alberta researchers are conducting clinical testing this year that will involve two patients with severe spinal cord injuries. A temporary bioelectronic device implanted on the lower spinal cord will transmit electrical impulses, mimicking brain signals, from below the spinal injury to the legs. They

ALL IMAGES: CVRX

Chicago Doctor Invents Affordable Hearing Aid

Outperforms Many Higher Priced Hearing Aids

Reported by J. Page

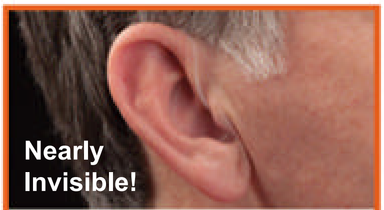
Chicago: Board-certified physician Dr. S. Cherukuri has done it once again with his newest invention of a medical grade **ALL DIGITAL affordable hearing aid.**

This new digital hearing aid is packed with all the features of $3,000 competitors at a mere fraction of the cost. **Now, most people with hearing loss are able to enjoy crystal clear, natural sound — in a crowd, on the phone, in the wind — without suffering through "whistling" and annoying background noise.**

New Digital Hearing Aid Outperforms Expensive Competitors

This sleek, lightweight, fully programmed hearing aid is the outgrowth of the digital revolution that is changing our world. While demand for "all things digital" caused most prices to plunge (consider DVD players and computers, which originally sold for thousands of dollars and today can be purchased for less), yet the cost of a digital medical hearing aid remains out of reach.

Dr. Cherukuri knew that many of his patients would benefit but couldn't afford the expense of these new digital hearing aids. Generally they are *not* covered by Medicare and most private health insurance.



SAME FEATURES AS EXPENSIVE HEARING AID COMPETITORS

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- ✓ **Wide Dynamic Range Compression makes soft sounds audible and loud sounds comfortable**
- ✓ **Telecoil setting for use with compatible phones, and looped environments like churches**
- ✓ **3 Programs and Volume Dial to accommodate most common types of hearing loss even in challenging listening environments**

The doctor evaluated all the high priced digital hearing aids on the market, broke them down to their base components, and then created his own affordable version — called the MDHearingAid®*AIR* for its virtually invisible, lightweight appearance.

Affordable Digital Technology

Using advanced digital technology, the **MD**HearingAid®***AIR*** automatically adjusts to your listening environment — prioritizing speech and de-emphasizing background noise. Experience all of the sounds you've been missing at a price you can afford. **This doctor designed and approved hearing aid comes with a full year's supply of long-life batteries. It delivers crisp, clear sound all day long and the soft flexible ear buds are so comfortable you won't realize you're wearing them.**

Try It Yourself At Home With Our 45-Day Risk-Free Trial

Of course, hearing is believing and we invite you to try it for yourself with our RISK-FREE 45-Day home trial. If you are not completely satisfied, simply return it within that time period for a full refund of your purchase price.

Can a hearing aid delay or prevent dementia?

A study by Johns Hopkins and National Institute on Aging researchers suggests older individuals with hearing loss are significantly more likely to develop dementia over time than those who retain their hearing. They suggest that an intervention — such as a hearing aid — could delay or prevent dementia by improving hearing!

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"Almost work too well. I am a teacher and hearing much better now" —Lillian Barden, California

"I have used many expensive hearing aids, some over $5,000. The Airs have greatly improved my enjoyment of life" —Som Y., Michigan

"I would definitely recommend them to my patients with hearing loss" —Amy S., Audiologist, Indiana

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hope the device will result in mobility.

"I don't think we'll get to the point where a drug will make a blind person see and deaf people hear," Ludwig says. But "that's what we're seeing with these devices."

THE ULTIMATE SMART PILL

Electrical treatments are unlikely to replace drugs, Ludwig says. Instead, he imagines them joining forces. For decades, drug pumps have been a "set it and forget it" type of treatment, delivering the same amount of drugs regardless of the patient's condition, says Ludwig. But a device that combines electrical treatments and drug pumps could target an area of the body, use sensors to read the patient's physiology and condition, and deliver the correct dose of drugs to just the right tissue.

Ludwig also envisions a novel combination treatment, part pharmaceutical and part bioelectronics: pills that dissolve into particles in the body, while an external power source, similar to today's ultrasound machines, would use magnetic fields to remotely direct the particles to different nerves. This futuristic medicine, currently in development, would eliminate the need for surgical implants. It would be the ultimate smart pill that could one day help treat cancer or Alzheimer's disease, Ludwig says.

Electrical medicine, such as this wireless pacemaker designed by Stanford, keeps getting smaller and more powerful.

AUSTIN YEE/STANFORD UNIVERSITY

In five to 10 years, we could see a device that's monitored via Bluetooth technology hooked up to an iPad at a doctor's office, Tracey says. And eventually, doctors will adjust their patients' devices over the Internet, just as they might adjust the pills a patient takes.

Ludwig agrees; he continues to see the devices advance every day. "That's really the power of it," he says. "There's no way of doing the equivalent with drugs." D

***Caroline Barlott** is a freelance writer whose work has appeared in* Reader's Digest, Canadian Geographic *and* Avenue Edmonton.

One Giant Leap

A healthy, stable woman with asthma suddenly finds herself considering suicide despite landing a dream job in a city she loves. What went wrong?

BY **DOUGLAS ADLER**

JONN/JOHNÉR IMAGES/CORBIS

Sandra slid the heavy window open. Smog and car exhaust wafted into her high-rise apartment. The sounds of the city on this Sunday afternoon were jarring and loud — the rumble of a subway train, a car honking, bus brakes squealing. In her bare feet, the 28-year-old woman climbed up and eased herself onto the window ledge, her legs dangling. The experience was vivid: the cityscape all around her, the wind blowing her hair into her eyes, the building's rough concrete scratching at her calves. Her heart beat faster as she watched the traffic far below, and she gathered up the strength to push off.

Thankfully, she didn't jump. Instead, she was in my hospital's emergency department an hour later. Sandra was sitting up on a stretcher, her legs crossed. She looked drawn and haggard, her hair an uncombed mess. I could tell she'd been crying and hadn't slept much. After a few questions, she began to tell me her story.

Several months earlier, Sandra landed her dream job in advertising and moved to the city from a small town. She was excited; things had been going well at work. Shortly after moving, she developed asthma, which is common among transplants to an urban environment with its poor air quality. Her physician tried treating her asthma with inhalers, but they weren't effective. She was switched to an oral steroid, which made breathing much easier.

On Saturday morning, Sandra awakened to a sudden and overwhelming feeling of sadness and emptiness, as if she were covered with a heavy, dark blanket. She couldn't think of anything that would cause this sudden change in mood; there were no troubles at her job or in her personal life. She had never felt this way before. As the morning and afternoon wore on, her depression deepened. Her phone rang several times, but she didn't have the emotional strength to answer it. She sat on her couch that day with the lights off and the shades drawn, not eating or drinking, alternating between crying uncontrollably and sitting in a near-catatonic state.

Her heart beat faster as she watched the traffic far below, and she gathered up the strength to push off.

That evening, Sandra climbed into bed and spent a restless night staring at the ceiling. She gave up trying to sleep and migrated from her bed back to the couch. Her mood darkened even more as the sun rose. By midafternoon

Sunday, still alone and spiraling down even further, she began to think of taking her life.

The idea shocked her at first, but the more Sandra thought about it, the more intense and compelling it became, almost slyly appealing. Over the next few hours, the notion built until, finally, in the late afternoon, as if in a trance, she opened her window and eased herself onto the sill. After what seemed to her like hours but likely lasted only a few minutes, her thoughts cleared for a moment, and she was struck by the incredible image of herself sitting out on the window ledge over a long drop. In a panic, she pulled herself back into her apartment and called 911.

This story of a suicide attempt is unusual. Many suicide attempts are triggered by what you might expect — long-standing depression or mental illness, a bad breakup, loss of a job, bankruptcy. There was no clear trigger that Sandra could recall; it all happened so quickly. She said her mood in the previous days had been great, even somewhat euphoric. She attributed her positive mood to the easing of her asthma symptoms.

When a person talks about euphoria turning abruptly to sadness, it often leads to a diagnosis of bipolar disorder, commonly known as manic-depressive illness. Yet some things about Sandra's story didn't fit with that scenario. Her euphoria was mild, and she didn't have the disorganized thoughts and behavior of a manic episode. She functioned well at work right up to the beginning of the depressive episode. She had no history of psychiatric disease. I wondered if she could have been experiencing hypomania — a less intense form of mania in which a person can still function at a high level — but I sensed something else was going on.

I asked if she took any medications. She said she didn't. When I mentioned that she had told me about her asthma medication, she said she finished her pills a few days ago and was "done with it." Asthma is a chronic condition, so this was an odd comment, especially from someone with a new diagnosis. A quick call to her pharmacy confirmed that her primary care physician had placed her on a high dose of an oral steroid for several weeks. And the pharmacist said she hadn't picked up her second prescription: a tapering dose of the same steroid.

Corticosteroids, more commonly known as steroids, are powerful hormones produced by our adrenal glands. Physicians prescribe them for many different conditions, frequently to reduce inflammation, as was the case with Sandra to treat her asthma. Steroids have many physiological effects, including regulating the immune system and metabolism. When a person takes high-dose steroids, the adrenal glands' function is suppressed. The body recognizes there are steroids in the bloodstream and responds by cutting back on (or altogether stopping) the production of its own steroids. On the other hand, if a person stops taking steroid medications, the adrenal glands will "wake up" and produce steroids again, but it takes time. Most high-dose steroid medications need to be tapered over weeks or months to give the adrenal glands time to recover.

Steroids also are widely known to alter mood and behavior. They can induce great happiness and severe depression, as well as psychosis and extreme anger. And yes, they can cause suicidal thoughts and suicide attempts.

Sandra had been on her steroid medication more than long enough to suppress her adrenal glands' steroid production. The clear improvement in Sandra's asthma and her mild euphoria were likely the result of those meds. But when she ran out of pills and stopped her medication without tapering off, the catastrophic drop in her blood steroid levels likely caused her sudden and severe depression. We restarted her on her steroid medication immediately.

Steroids are widely known to alter mood and behavior. They can induce great happiness and severe depression, as well as psychosis and extreme anger.

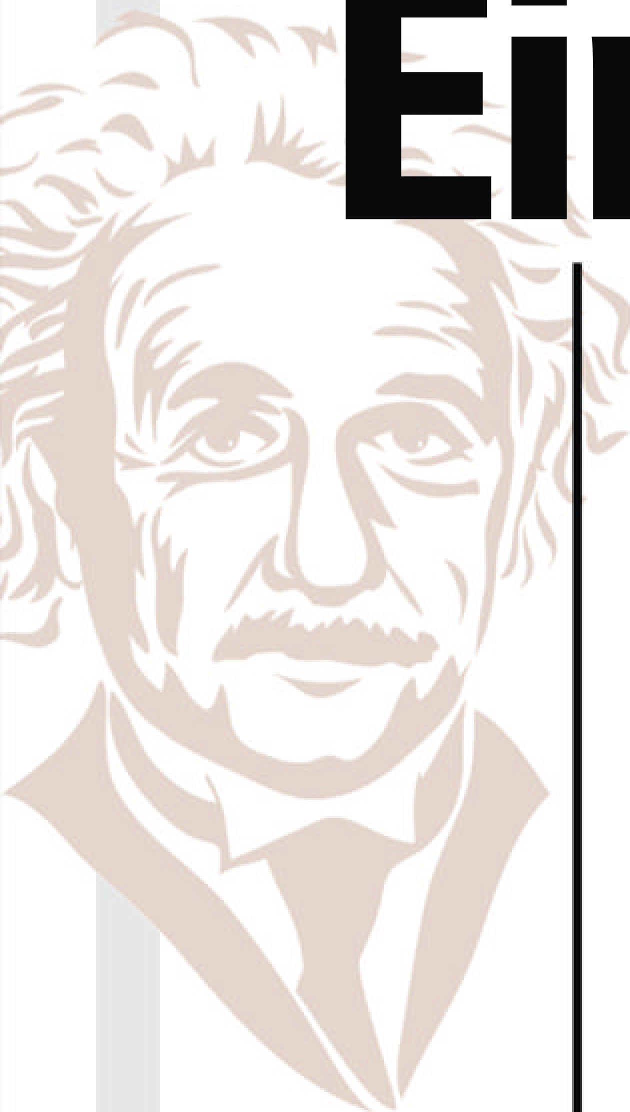
When I visited her the following evening, it was like seeing a completely different person. The disheveled woman I had met was well-dressed and groomed and feeling much more like herself. All thoughts of suicide had vanished. Sandra was discharged the next day, after a slow steroid taper to allow her adrenal glands to restart on their own.

Sandra's experience illustrates the powerful role medications can have on the brain and behavior. It also demonstrates how a superficial analysis of her symptoms could have sparked a misdiagnosis of a primary psychiatric disorder — and committed Sandra to a psychiatric hospital for weeks. Medicine is full of close calls, but Sandra's was about as close as they come. D

***Douglas Adler** is an associate professor of medicine at the University of Utah School of Medicine in Salt Lake City. The cases described in Vital Signs are real, but names and certain details have been changed.*

Special Section

Outsmarting Einstein



After a century of testing general relativity, physicists still strive to achieve what the genius who formulated the theory could not.

BY **BILL ANDREWS**

Albert Einstein single-handedly changed the universe 100 years ago. For centuries, Isaac Newton's straightforward equations ruled the cosmos — or at least how physicists thought about it. Any object with mass exerted an attractive force on any other object with mass; the bigger the masses, and the closer the two objects, the stronger the attraction. Simple. But in 1915, Einstein suggested that things were a bit trickier.

Even Einstein had to labor for almost a decade to formulate the complex mathematical relationships behind his magnum opus, his own version of gravity: the general theory of relativity. Gravitational attraction, it turned out, was due to nothing less than the warping of the cosmos. A massive object literally bends the three-dimensional fabric of the universe around it, taking any smaller objects in the vicinity along for the ride. This results in familiar phenomena like orbiting moons, planets and stars, as well as some stranger effects like cosmic ripples and black holes.

And, surprise, it turns out that Einstein was right. But, as we'll see in the following pages, even after a century of confirmation, physicists' growing technological arsenal means they are still eager to poke and prod the theory, anxious to see if it holds up. They do this partly just to possibly outsmart one of history's top scientific minds, but mostly out of the same insatiable scientific curiosity that led Einstein to formulate the theory in the first place.

The rest of his life, Einstein tried to combine all the known forces of the universe (including his version of gravity) into one simple set of rules, but the answer eluded him. Some 60 years after his death, scientists still hope to unify the forces. Testing relativity might just turn up a key clue in the quest. Physicists may be able to do what Einstein never could if they find out where, if ever, nature begins to disagree with general relativity.

Whatever it was that fueled Einstein's insights into the universe — whether it was an extraordinary brain or just the way he looked at the world — his work has lasted at least 100 years intact. Maybe it always will. But perhaps, in the next 100, someone else will have changed the universe once more.

THIS PAGE: CONNIE LARSEN/DREAMSTIME.COM. OPPOSITE: PHOTOGRAPHS BY ESTHER BUBLEY, COPYRIGHT JEAN BUBLEY

These photos and outtakes for Life *magazine (some never before published) capture Albert Einstein's 74th birthday in 1953, an unusually public day for the private scientist. Guests poured in to help him celebrate Yeshiva University's naming its new medical school after him.*

View an interactive timeline and test your Einstein IQ at **DiscoverMagazine.com/Einstein**

Putting Relativity to the Test

When he unveiled his general theory of relativity, Albert Einstein wasn't exactly met with applause. Almost no one else could do the math necessary to understand his abstract ideas, and at the time he didn't have any evidence to back it up. But in the century since it was proposed, Einstein's theory has continued to pass ever more stringent tests.

It remains our best explanation of the phenomenon of gravity. The theory bears out all sorts of wild predictions, the bulk of which boil down to this: Gravitation behaves the same for all observers, resulting from curving "space-time," the fabric of the universe.

Einstein's concepts have been verified — just as he reckoned they would — on scales from a foot-long sub sandwich to galaxy clusters millions of light-years wide. In between, general relativity has made its mark on the Global Positioning System, while explaining anomalous planetary orbits and the whirling death dances of the remnants of giant stars.

"We're still using the same theory that was invented a hundred years ago, and it still works amazingly well in so many different situations," says physicist Clifford Will of the University of Florida.

Here are six examples of how Einstein's landmark theory has stood the test of (space-)time.

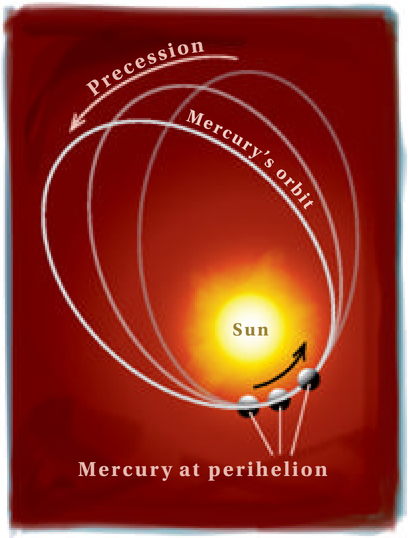
BY **ADAM HADHAZY**
ILLUSTRATIONS BY **ROEN KELLY**

1. MERCURY, THE GLITCH IN NEWTON'S MATRIX

The Perihelion Precession of Mercury

Isaac Newton's law of gravity saw perhaps its greatest triumph in the mid-1800s with the discovery of the planet Neptune. In 1846, French mathematician Urbain Le Verrier crunched the numbers on Uranus' weird orbit, likely caused by another massive body, and just a few months later German astronomers spotted Neptune lurking right where Newton's laws predicted. Ironically, it was another orbital discrepancy that turned out to be the chink in Newton's armor, which Einstein's ideas blew wide open.

In 1859, Le Verrier pointed out that the planet Mercury was arriving at its closest orbital position to the sun, called perihelion, a half-second behind schedule.



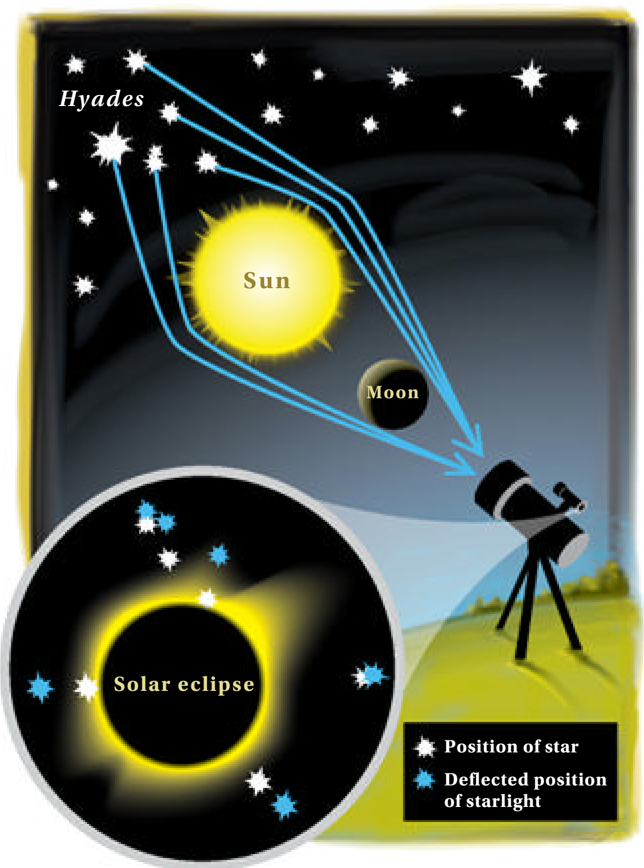
"Mercury was not quite behaving the way Newton said it should," says Daniel Holz, a professor of physics at the University of Chicago.

This so-called precession of Mercury's perihelion wasn't much; it worked out to a break per orbit of a mere millionth of a percent from Newtonian predictions. Yet with each go-round (Mercury has an 88-day year), the planet stubbornly appeared out of place during perihelion from where astronomers expected it.

At first they assumed that, as with the Uranus solution, another planet must exist even closer to the sun, affecting Mercury's orbit. The conjectured world even got a name, Vulcan. Decades of searching failed to reveal the scorched world.

In stepped Einstein. In 1915, his brand-new theory precisely accounted for Mercury's weirdness, ultimately due to the warping of space-time produced by the substantial mass of the sun.

Similar perihelion precessions, all in perfect agreement with general relativity, have been subsequently documented for other star systems, namely binary pulsars. These pairs of neutron stars — the ultra-dense remains of collapsed, behemoth stars — whip around each other exactly as Einstein said such things should, although no one even conceived of these objects until the 1930s.



2. BEND IT LIKE EINSTEIN

The Deflection of Light by Cosmic Bodies

Einstein's initial success with explaining away the Mercury conundrum did not catapult him to superstar status. Those accolades actually came a few years later, with the verification of another of general relativity's bold prognostications: Massive objects such as the sun should warp space-time enough to throw passing rays of light off course.

Einstein's work piqued the interest of English astronomer Arthur Eddington, who recognized a great opportunity to test for this light deflection: On May 29, 1919, the sun would conveniently undergo a solar eclipse, which would block out its overwhelming glare, while passing close to a bright group of background stars called the Hyades. If Einstein were right, the sun's presence would deflect their light, subtly shifting their position in the sky.

Eddington arranged a pair of expeditions (one to Sobral, Brazil, and another to Principe, an island off the west coast of Africa) to look for the bending of the Hyades' starlight as the eclipse shadow swept through West Africa and Brazil. Sure enough, the tiny predicted displacement of the stars' light showed up.

The news of this discovery made headlines worldwide, with the Nov. 7 *London Times* proclaiming: "Revolution in Science/New Theory of the Universe/Newtonian Ideas Overthrown." Einstein, remarkably for a physicist, became a household name.

The "gravitational lens" created by the bending of light through warped space-time has become a vital tool in probing the cosmos. "I call it Einstein's gift to astronomy," says Will. Foreground galaxy clusters can warp and magnify the light of distant, background proto-galaxies, for instance, allowing cosmologists to catch glimpses of early epochs of the universe.

3. STRETCHING LIGHT AND TIME

The Gravitational Redshifting of Light

Along with the two prior predictions, this third example rounds out the three classical tests that Einstein considered critical to prove general relativity, and it's the only one he didn't live to see.

Relativity posits that as light moves away from a massive object, gravity's curving of space-time stretches the light out, increasing its wavelength. With light, wavelength equates to energy and color; less energetic light trends toward the redder part of the spectrum than shorter-wavelength, bluer light. The predicted gravitational "redshifting" effect was too meager for detection for decades, but in 1959, Harvard physicist Robert Pound and his grad student, Glen Rebka Jr., had an idea.

They set up a sample of radioactive iron in an elevator shaft of a Harvard building, letting the radiation travel from the basement to the roof, where they'd set up a detector. Although the span was a measly 74 feet, it was enough for the gamma rays to lose a couple trillionths of a percent of their energy due to our massive planet's gravitational warping of space-time, in the ballpark of Einstein's predictions.

To really nail down this relativistic effect, NASA launched its Gravity Probe A rocket in 1976. This time, researchers looked for a change in the frequency of waves — with shorter wavelengths meaning a higher frequency, and vice versa — in a type of laser in atomic clocks. At a peak altitude of 6,200 miles, a clock aboard Gravity Probe A ran ever so slightly faster than a clock on the ground. The difference, a mere 70 parts per million, matched Einstein's math with unprecedented precision.

In 2010, scientists at the National Institute of Standards and Technology went even further, showing that at just 1 foot higher in elevation, a clock ticks four-hundred-quadrillionths faster per second. The takeaway: Your head ages *ever so slightly* faster than your feet.

"That was a fantastic experiment, just to be able to measure the difference in the rate of time over that very small amount of distance," says Will.

On a more practical scale, the same effect impacts the Global Positioning System, whose orbiting satellites have to be adjusted thirty-eight-millionths of a second per day to stay in sync with Earth's surface. "Without that correction," says Will, "GPS wouldn't work."

4. LIGHT, INTERRUPTED

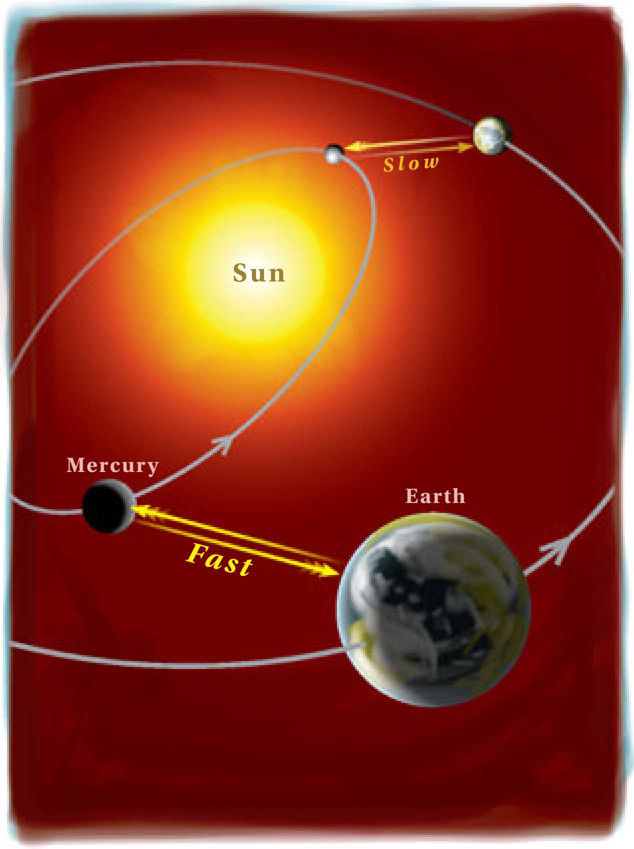
The Shapiro Effect: The Relativistic Delay of Light

Often dubbed the fourth classical test of general relativity, and the brainchild of Harvard physicist Irwin Shapiro, this experiment timed how long it took light to travel from A to B and back. If Einstein was on the money, it would take that light longer if there were a massive object near the path.

In the early 1960s, Shapiro proposed testing this by bouncing a radar signal off of Mercury when the planet was situated right next to the sun (from our Earthly perspective). Shapiro calculated that the sun's gravity well should delay the radar signal by about two-hundred-millionths of a second, compared with its time back from Mercury without the sun nearby. "That's not exactly an eternity," Shapiro says.

Tests began in 1966, using the 120-foot-wide radio antenna at MIT's Haystack Observatory. The echo from Mercury closely corresponded to Shapiro's reckonings. Still, close wasn't good enough; all it took was a teensy anomaly in Mercury's orbit to overthrow Newton's laws, after all.

So, to verify the Shapiro effect further, physicists abandoned planets, whose rough surfaces scatter some of the radar signals, for smoother targets: spacecraft. In 1979, the Viking landers on Mars made for a good testing ground for the Shapiro time delay. Then, in 2003, Italian researchers detected a time delay in communication signals to the Cassini spacecraft en route to Saturn. The accuracy achieved was 20 parts per million, 50 times better than even the Viking results, and — wouldn't you know it — right in line with general relativity.



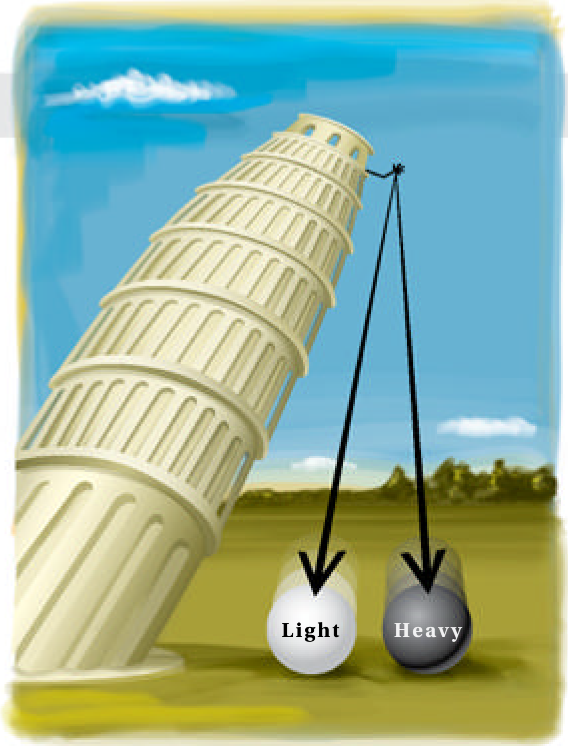
5. DROPPING SCIENCE

The Equivalence Principle

At the heart of general relativity lies the equivalence principle. It states that bodies "fall" at the same rate through a gravitational field, regardless of their mass or structure. Building on this idea, the principle also holds that other physical laws within a given reference frame should operate independently of the local strength of gravity; in other words, the coin you flip when cruising on an airplane flips the same as one on the ground. Generally, experiments should reach the same results regardless of where and when in the universe they take place. Therefore, the laws of nature must be the same everywhere and throughout time, stretching all the way back to the Big Bang.

First, the easy part. Evidence supporting the first aspect of the equivalence principle initially came four centuries ago. In 1589, famed Italian astronomer Galileo Galilei, perhaps apocryphally, released balls from atop the Leaning Tower of Pisa. The balls, though made of different materials, met little air resistance and landed at the same time. Presto! Four centuries later, in 1971, a more evocative demonstration took place on — of all places — the moon. During the Apollo 15 mission, astronaut Dave Scott simultaneously let go of a hammer and a feather. In the airless lunar environment, the objects fell together and struck the lunar surface simultaneously, mirroring Galileo's experiment. The two bodies fell at the same rate, despite their differences.

Apollo astronauts also left behind reflectors on the moon's surface. These fancy mirrors have enabled scientists to bounce lasers off the moon to precisely measure its position relative to Earth, down to four-hundredths of an inch. These readings have offered a rigorous test of the "falling equivalently" concept, as well as its related notion that nature's laws must apply equally everywhere. To date, decades of data from these lunar laser ranging experiments have agreed with general relativity down to trillionths of a percent.



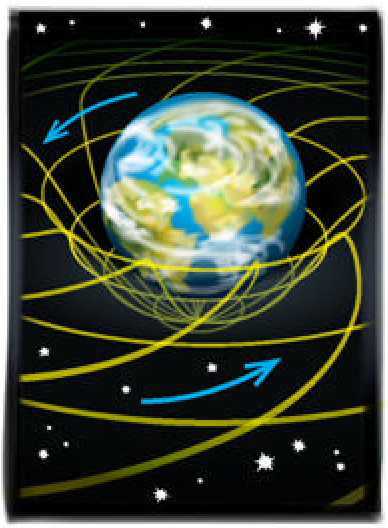
The setup has also pegged the moon's acceleration toward the sun as the same as Earth's, just like Galileo's and Scott's dropped objects. After all, according to the equivalence principle, "you are in effect dropping the Earth and the moon around the sun," says the University of Chicago's Holz.

6. SPACE-TIME, SPUN AND DRAGGED

The Geodetic and Frame-Dragging Effects

Einstein's conception of space-time is actually sort of gelatinous. A well-known analogy illustrating this idea is imagining Earth as a bowling ball placed on a trampoline. The massive Earth dents the fabric of the space-time trampoline, such that an object rolling near the planet/ball will have its trajectory altered by Earth's gravitational warping. But the trampoline analogy is only part of the general relativity picture. If the theory is correct, a spinning massive body pulls space-time along with it, akin to a spoon spun in honey.

Circa 1960, physicists dreamed up a straightforward experiment to examine both of these predictions. Step 1: Place gyroscopes on board a satellite orbiting Earth. Step 2: Align the spacecraft and the gyroscopes with a reference star, serving as a basis for comparison. Step 3:



Look for changes in the alignment of the gyroscopes, seeing how far out of alignment they'd been dragged by Earth's gravitational influence.

Later christened Gravity Probe B (a sequel of sorts to Gravity Probe A), the test only became technologically possible 44 years (and $750 million) later. The results, announced in 2011, were hard won: Despite unprecedented precision and patient waiting, tiny misalignments still made data analysis a challenge. But, in the end, the measurements again buttressed Einstein. Earth's spin really does drag space-time along with it.

General relativity has held up quite well these last 10 decades. But its trials are far from over. As impressive and rigorous as many of the tests have been, none have taken place in the realm of monstrously strong gravity, in the neighborhood of black holes. In these extreme environments, Einstein's theories might just come undone, or — given the man's track record — astound us still more with their predictive power.

"We're really looking at probing the predictions of general relativity even more deeply," says Will. "We shouldn't give up testing it." D

__Adam Hadhazy__ is a freelance science writer based in New Jersey. He also writes for Popular Science *and* Scientific American*'s website, among other publications.*

Defying Gravity

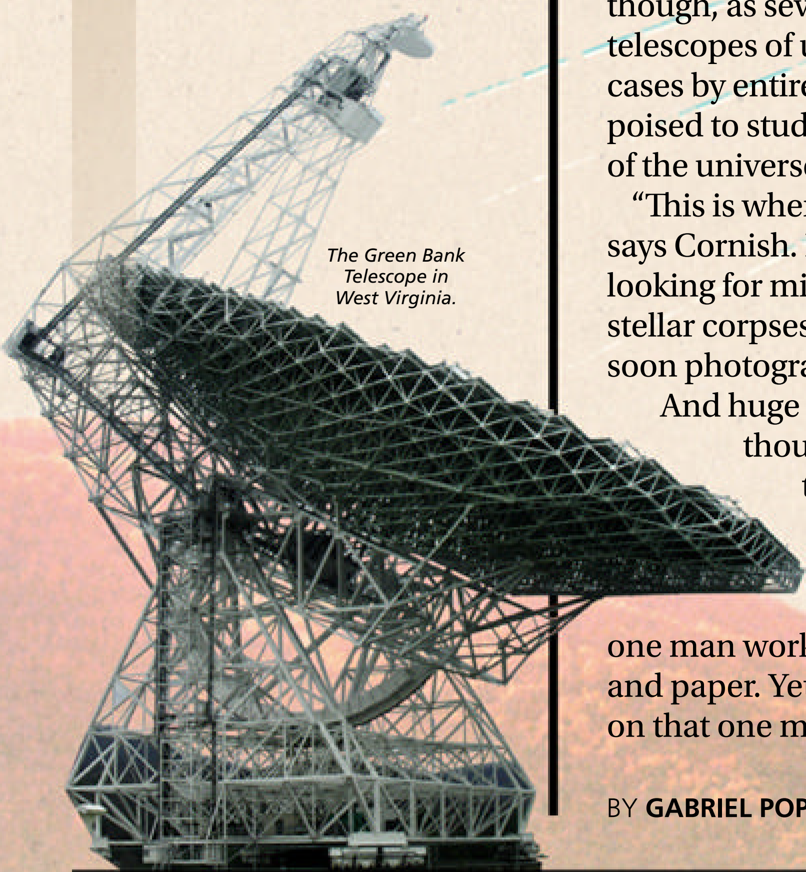
Albert Einstein's general theory of relativity remade gravity and solved problems that Newton's theory couldn't. It's passed each of the dozens of experimental tests devised since its debut in 1915. But physicists have barely gotten started.

"We've only been playing around in Newton's world so far," says Neil Cornish, a physicist at Montana State University. That will soon change, though, as several bold experiments enabled by telescopes of unprecedented reach — and in some cases by entirely new ways to gather data — are poised to study how gravity behaves around some of the universe's most extreme objects.

"This is where general relativity really gets going," says Cornish. Powerful telescopes are already looking for minute hiccups in the whirring of stellar corpses called pulsars. A global effort will soon photograph, for the first time, a black hole. And huge gravitational wave detectors will scan thousands of galaxies for tiny ripples in the cosmic fabric of space-time.

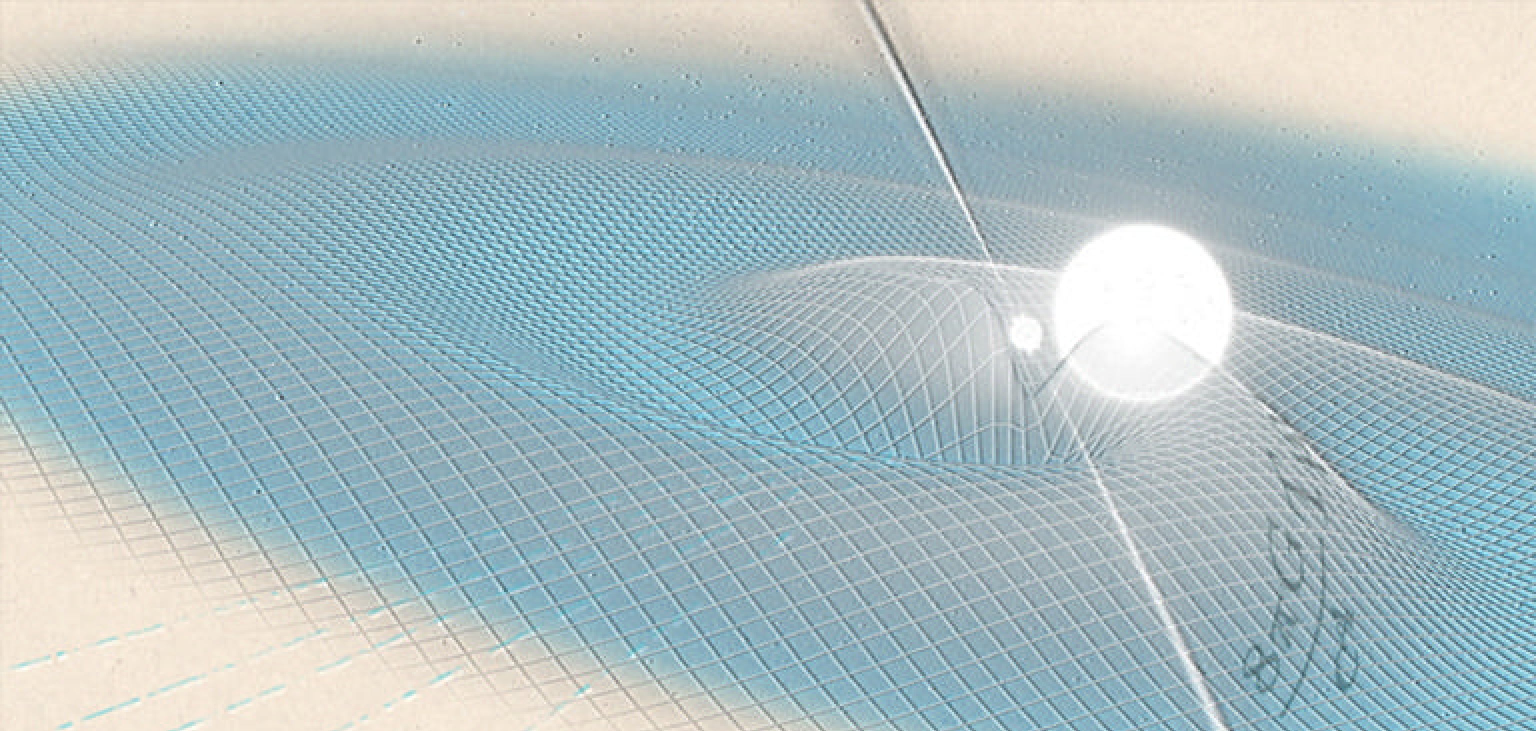
Each of these experiments — some of the most ambitious ever conceived — will test a theory that one man worked out a century ago with pencil and paper. Yet most physicists are still betting on that one man.

BY **GABRIEL POPKIN** ILLUSTRATIONS BY **KELLIE JAEGER**



The Green Bank Telescope in West Virginia.

GREEN BANK RADIO TELESCOPE: PETER BASSETT/SCIENCE SOURCE



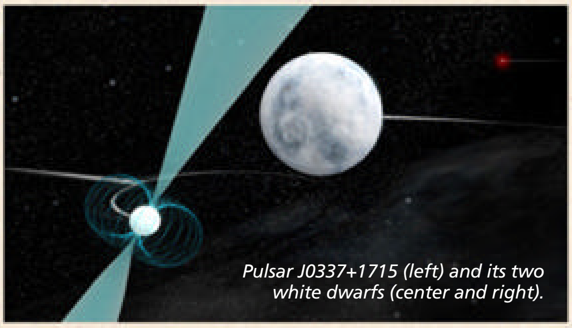
TAKING GRAVITY'S PULSE

With today's advanced instruments, astronomers can for the first time search the universe's gravitational extremes for relativity's possible breaking point. New telescopes and detectors are helping astronomers look far beyond the solar system, where nearly all tests so far have occurred. They aim to detect how gravity behaves in the highly warped regions of space-time near superdense collapsed stars called pulsars. These extreme objects advertise their presence with intense beams of radiation, sweeping through the sky like cosmic lighthouses, with a regularity rivaling Earth's best clocks. They're so tightly packed that a pulsar the mass of our sun would be compressed to a sphere with a diameter about the length of Manhattan.

One of the more famous general relativity tests to date involved a pair of pulsars, technically named PSR B1913+16 but better known as the Hulse-Taylor binary pulsar (after Russell Hulse and Joseph Taylor, who won the 1993 Nobel Prize in Physics for its discovery). Einstein predicted that as dense objects like pulsars orbit each other, they should create ripples in space-time, similar to ripples in a lake. Called gravitational waves, these undulations are so tiny that one passing through Earth would jostle us by far less than the diameter of a proton.

Over time, however, the outgoing gravitational waves would deplete a binary system's energy, causing the objects to spiral in toward each other. Over a 30-year study period, the Hulse-Taylor pulsars spiraled toward one another at exactly the rate Einstein predicted.

Ever since Hulse and Taylor stumbled upon their pulsars in 1974, astronomers have turned up thousands more throughout the galaxy. One of these recently discovered pulsars, with a highly unusual orbit involving two other stars known as white dwarfs, can now help physicists test a different prediction of general relativity. Scott Ransom and his colleagues at the National Radio Astronomy Observatory are using the Green Bank Telescope in West Virginia to track the rotation of this odd pulsar, designated PSR J0337+1715. The system's unique geometry will allow the scientists to examine general relativity's strong equivalence principle, which states that gravity accelerates all objects at the same rate, regardless of their density.


Pulsar J0337+1715 (left) and its two white dwarfs (center and right).

When a star collapses into an ultradense object like a pulsar or black hole, some of its matter turns into what's called gravitational binding energy. (Part of an ordinary star or white dwarf also exists as this energy, but a much smaller fraction.) Einstein's theory predicts that such energy should experience the same gravitational attraction as matter, meaning that Ransom's pulsar and the white dwarf orbiting near it

TOP: ESO/L. CALÇADA. INSET: BILL SAXTON/NRAO/AUI/NSF

would be drawn toward the system's third star at the same rate. If, by contrast, the rates were to vary, the pulsar's orbit would be distorted, and Ransom and his colleagues could use the timing of the pulses to detect this distortion. In this way, the researchers expect to test whether the strong equivalence principle holds. The results will be 20 times — possibly 100 times or more — more precise than ever before.

Ransom expects the results by mid-2015, but he isn't betting against Einstein. "In all likelihood, general relativity will pass this as well," he says. "But we'll never find what, if anything, is wrong with relativity unless we keep trying."

BALD BLACK HOLES

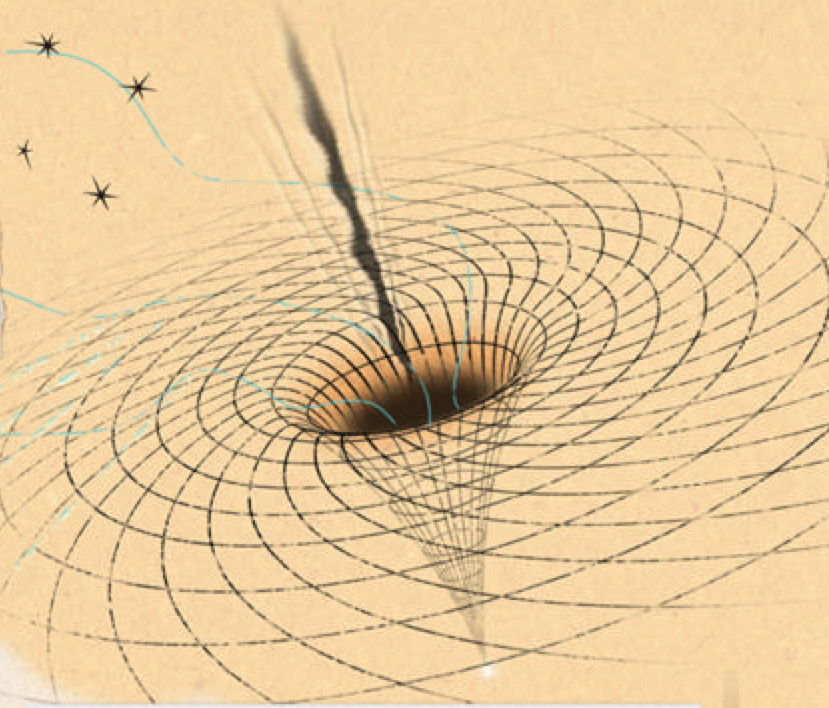
While pulsars are certainly compact objects, the true gravitational heavyweights are black holes. Dimitrios Psaltis, an astrophysicist at the University of Arizona, is helping to test what may be general relativity's most extreme prediction: that large-enough stars will eventually collapse under their own gravity to form these infinitely dense objects. Despite decades of data implying the existence of black holes, all the evidence is circumstantial, based on observations of their effects on light or other objects, Psaltis says. Black holes themselves have yet to be directly observed.

Seeing is believing, so Psaltis and his colleagues hope to take a direct photo of Sagittarius A*, the monstrous black hole that astronomers suspect lurks at the center of our galaxy. To do this, the researchers will use the Event Horizon Telescope (EHT) — a combination of more than 10 radio telescopes and telescope arrays scattered across the planet — which should be able to see all the way to the edge of Sagittarius A*, some 26,000 light-years away. Psaltis and his colleagues suspect the black hole will cast a circular shadow amid a radio-wave background.

In addition to proving that black holes exist, Psaltis says the EHT should also confirm or challenge another key tenet of relativity, the no-hair theorem. The eminent theoretical physicist John Archibald Wheeler quipped that "black holes have no hair," meaning they're all identical except for three key distinguishing characteristics: mass, rotation and a vanishingly small electric charge. Any "hair" — essentially, any specific information about what goes into the black hole, like an object's chemical composition or molecular structure, or even just shape and size — is lost forever within the black hole's event horizon.

With the EHT, Psaltis and his team plan to study the size and shape of the shadow that Sagittarius A* casts. General relativity's no-hair theorem predicts an almost perfectly circular shadow; modifications to general relativity in which black holes retain their hair could yield an ellipsoidal one. Also hoping to probe the theorem, University of Florida physicist Clifford Will suggested a test to track how ordinary stars near Sagittarius A* move, and Norbert Wex and Michael Kramer at the Max Planck Institute for Radio Astronomy in Germany hope to do the same with one or more pulsars, though they first need to find one that is close enough. Black hole hair would change how such objects orbit near the hole, and these changes could be detectable by telescopes that will come online within the next decade.

"If we do find that the no-hair theorem is not satisfied, that would really be a major blow to the theory, or to black holes," says Psaltis. It would be a surprise, he acknowledges, but sooner or later, something unexpected has to show up. "And in gravity, like in most places in physics, whenever we open a window on somewhere we've never looked, we always find a surprise."



GAZING AT GRAVITY

Finally, one set of experiments will probe relativity not by collecting and analyzing light from cosmological bodies, but by looking at gravity itself. The Laser Interferometer Gravitational-Wave Observatory (LIGO) and a companion experiment named Virgo will search out those cosmic ripples, or gravitational waves, emanating from galaxies hundreds of millions of light-years away.

In the observatories' giant L-shaped facilities, lasers shine down several-mile-long tunnels and bounce back and forth between mirrors and into detectors. The observatories are so exquisitely tuned that they can sense the slight push and pull of gravitational waves — one-thousandth a proton's width of difference — on the mirrors. These tiny tugs will create telltale patterns as the detectors collect the laser light. Physicists can then analyze the data for clues about the far-off events that set the undulations in motion.

LIGO has operated detectors in Livingston, La., and Hanford, Wash., since 2002; the Virgo detectors in Cascina, Italy, took data in a network with LIGO detectors in 2007 and in 2009-2010. None of these efforts detected a gravitational wave — a disappointing, but not unexpected, result. Both the Livingston and Hanford observatories are now wrapping up major overhauls that will allow them to scan 1,000 times more space than before. By 2018, they should be sensitive enough to detect gravitational waves originating from tens of thousands, if not hundreds of thousands, of galaxies, according to physicist and LIGO spokeswoman Gabriela Gonzalez.

Data from these waves will test Einstein's predictions about how fast black holes spin and exactly what happens when they smash into neutron stars and into each other. These events will be dramatic: In terms of energy, two merging black holes should "outshine every star in every galaxy in the universe in their final moments," says Montana State's Cornish, who studies how to make sense of the data that will soon pour in from LIGO, Virgo and other gravitational wave experiments. Unexpected signals in the data could force revisions to the theory, Gonzalez says, but she adds, "I don't expect we will prove relativity wrong."

The LIGO facility in Livingston, La.

STILL BETTING ON EINSTEIN

Einstein never really doubted general relativity. When asked about the possibility of an early test disproving his theory, he responded, "Then I would feel sorry for the dear Lord. The theory is correct anyway." Most of today's physicists agree, based on its track record. "Personally, I would not be surprised if general relativity survives all of these things," says the University of Florida's Will.

If relativity does succumb, it would be exciting, but the exhilaration would be bittersweet. Physicists would have to part with one of their most beautiful theories — one that provides extraordinarily deep insight into the universe from a remarkably economical set of starting assumptions, says Cornish. "It really is an incredibly elegant theory." D

***Gabriel Popkin** is a science and environmental writer based in Mount Rainier, Md. He writes frequently about physics and has been fascinated by relativity since fourth grade.*

Beyond Einstein

Why are researchers so intent on proving Einstein right or wrong? It's not simply that he is a towering figure whose name is synonymous with genius, someone whose work has profoundly shaped physics for more than a century.

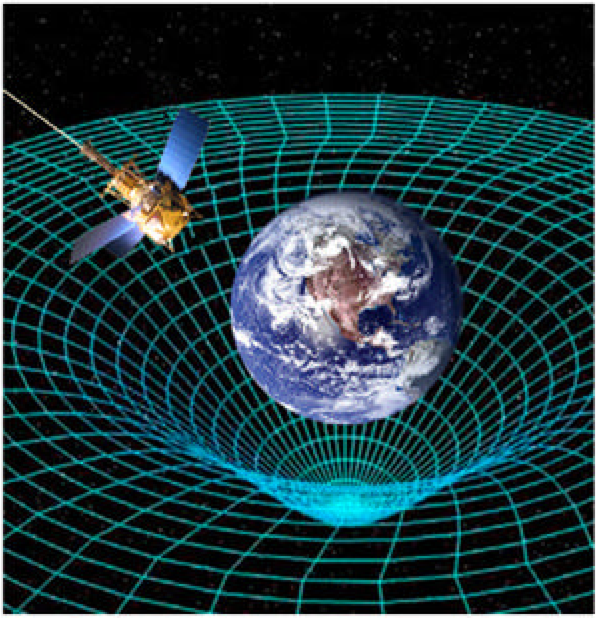
Instead, much of the incentive stems from gravity itself, which has been something of a problem child in the field. Physicists, including Einstein, have long hoped to devise a unified theory of the universe, but they've struggled to get gravity to mesh with the other fundamental forces. As a result, we currently have a theory of gravity (Einstein's general relativity) and a separate theory of everything else (the "standard model" of particle physics). Unfortunately, these two extremely successful theories are incompatible with each other — and sometimes even contradictory.

This arrangement just won't do for physicists, who believe there ought to be a single theory of nature that covers everything. Clues for achieving the long-sought unification may come from a better understanding of how — and under what circumstances — general relativity breaks down.

That's why investigators have been pushing the theory to the max, trying to see where it falters in order to figure out the best way to connect gravity with the rest of physics.

BY **STEVE NADIS**

WILLIAM HORACE SMITH/CORBIS



Gravity Probe B measured exactly how much Earth's gravity warped the space-time surrounding it, ultimately vindicating Einstein's calculations.

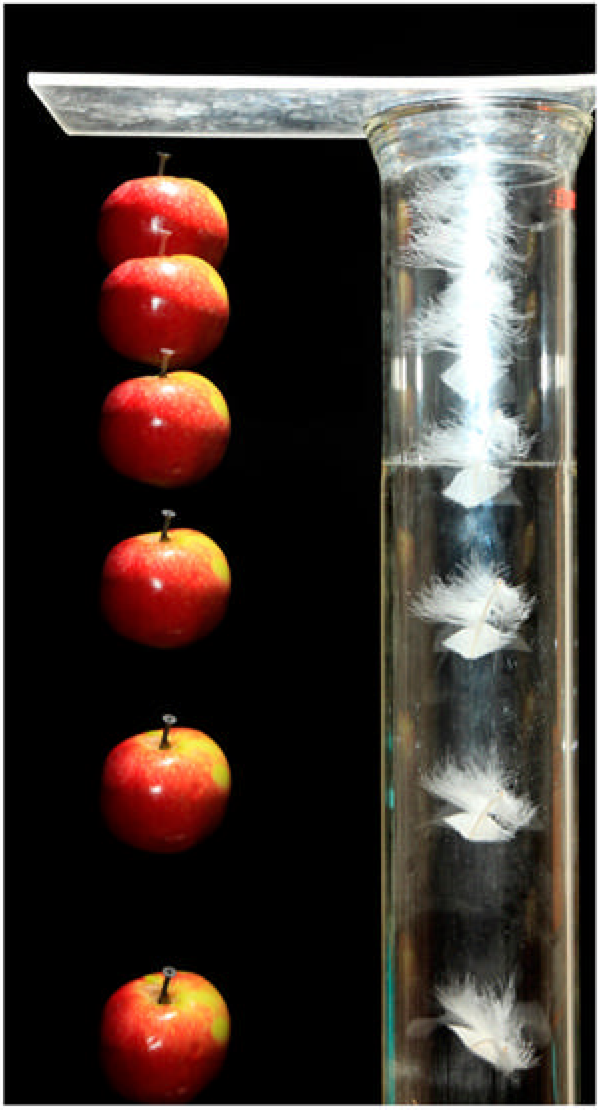
IT'S ALL EQUIVALENT

Researchers see the equivalence principle, a central tenet of general relativity, as a promising avenue of attack that could steer them toward an ultimate theory of everything. Simply put, the equivalence principle holds that all bodies under the influence of the same gravitational field experience the same acceleration, regardless of their mass or composition.

One advantage of this strategy is that, so far, every credible attempt at crafting a unified theory introduces new forces that would cause ever-so-slight changes in the way matter interacts with gravity. If these theories are correct, and we look closely enough, we should see "EP violations," tiny departures from the equivalence principle. In other words, a gold brick should fall somewhat differently from one made of silver, and a detailed analysis of those differences could provide valuable hints for physicists trying to construct a correct unified theory.

"We don't know the level at which a violation [of the equivalence principle] will show up, but we do believe there should be one," says Thibault Damour, a theorist at IHES (Institut des Hautes Études Scientifiques) in France. The reason, Damour adds, is that "all attempts to unify Einstein's theories with the other forces" — an endeavor he considers essential to the field — "lead to EP violations."

Experiments conducted on Earth have shown the principle to be valid to a precision of 1 part in 10 trillion. But a space-based experiment called STEP



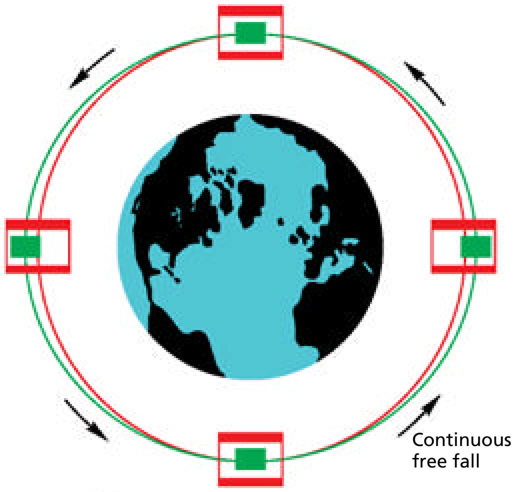
The equivalence principle in action: Because the feather falls in an airless tube, it experiences no wind resistance, meaning it and the heavier apple fall at exactly the same rate in Earth's gravity field.

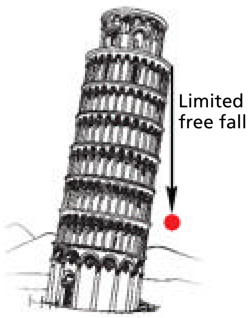
(Satellite Test of the Equivalence Principle) could pose a much sterner challenge, boosting the accuracy of these measurements by a factor of 100,000. That kind of precision could be enough to show physicists just where Einstein's theories start to miss the mark — assuming they do.

THE NEXT STEP

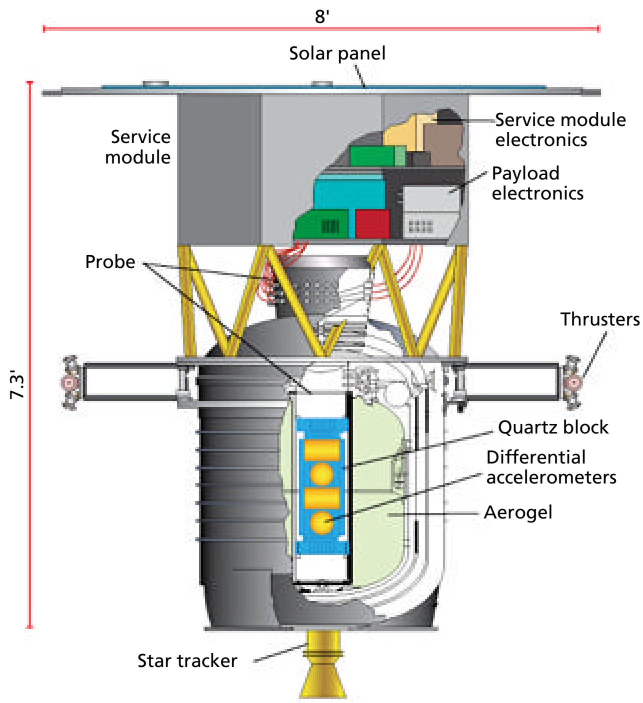
STEP began in 1971 as a thesis project by then-graduate student Paul Worden, with Stanford physicist Francis Everitt serving on the thesis committee and then as the project's chief scientist soon afterward. Everitt has devoted a half-century of his life to testing general relativity and was the principal investigator

LEFT: NASA. RIGHT: TED KINSMAN/SCIENCE SOURCE





THE EXPERIMENT: The Satellite Test of the Equivalence Principle (STEP) is essentially a more precise re-creation of Galileo's famed experiment. Instead of testing the acceleration of different masses as they fall from the Leaning Tower of Pisa, scientists will watch for discrepancies in objects (green box) falling while in orbit.



THE EQUIPMENT: STEP should produce results accurate to at least 1 in a quadrillion, so it needs extremely precise equipment. The team should be able to minimize disturbances by operating the satellite at near-absolute-zero temperatures and burying the test masses and accelerometers within the hypersensitive probe.

of Gravity Probe B, a NASA-funded satellite mission that studied, and eventually verified, another aspect of Einstein's theory.

By going into space like Gravity Probe B, STEP could dramatically improve the precision of equivalence principle measurements. These measurements are hard to do on the ground owing to vibrations from street traffic, Earth tremors and other disturbances. Space

Francis Everitt, principal investigator for NASA's successful Gravity Probe B mission, hopes to see STEP launch one day.

offers a much calmer environment.

Another advantage relates to observation time, suggests Towson University physicist James Overduin, who has worked on STEP, intermittently, since 1999. If you drop balls of different size from the Leaning Tower of Pisa, for example, their free fall lasts just seconds. "But you can drop things in space, and they never stop falling," Overduin says; they remain in orbit, constantly falling toward Earth. This allows an extended time — days or longer — to look for subtle effects.

The plan calls for using four pairs of "test masses" made of at least three different materials — such as beryllium, niobium and platinum-iridium — which would be kept in a vacuum and cooled to just a few kelvins, reducing temperature fluctuations that can degrade measurement accuracy. Materials are chosen to reflect the broadest possible range of chemical properties so that disparities in acceleration (detected by an onboard accelerometer) would be the easiest to spot. The point, again, is to make meticulous measurements that show whether objects of different composition fall at different rates.

Although years have passed since STEP's inception, Everitt hasn't stopped trying to get the project off the ground. The proposed mission received research and development support for decades. It has been endorsed

TOP: JAY SMITH AFTER STEP AND FUNDAMENTAL PHYSICS, ARXIV.ORG/PDF/1401.4784V1; LEANING TOWER BY TERRIANA/THINKSTOCK. BOTTOM: NASA/ PAUL E. ALERS

by prestigious review panels assembled by NASA and the European Space Agency, and it has been praised by former NASA head Dan Goldin. But the project has never quite mustered the requisite financial backing, despite Everitt's tireless lobbying efforts.

Mark Lee, a senior program scientist at NASA, still believes in STEP, calling it "one of the most critical fundamental physics experiments that mankind could pursue." The bad news for STEP, he says, is that after 2004, NASA's fundamental physics program was terminated. Since then, it has been only partially revived.

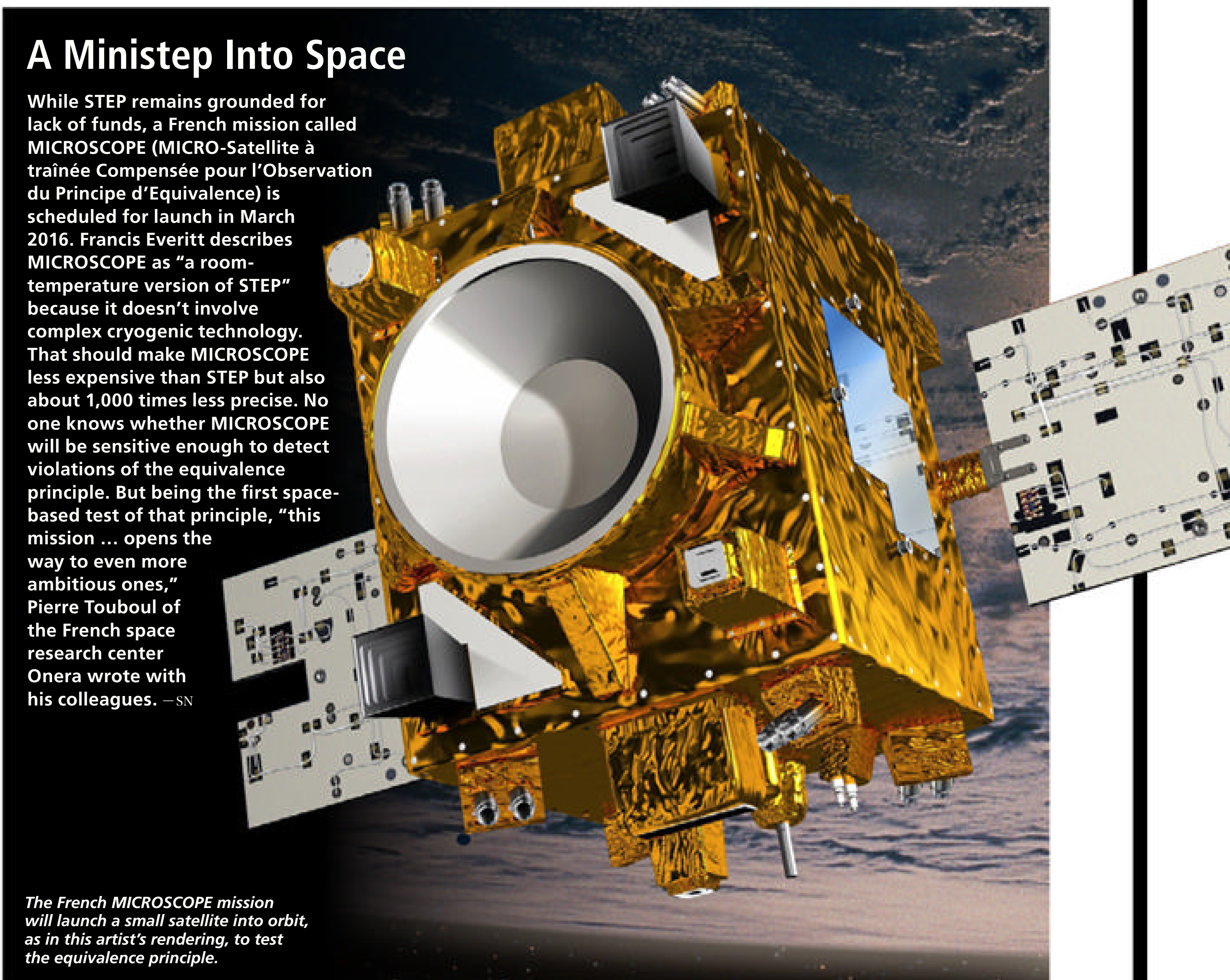
Everitt remains hopeful, nevertheless. He spent 40 years working on Gravity Probe B before that satellite's launch in 2004. He's also spent 40 years pushing the development of STEP and is not ready to walk away from it yet, even though he just turned 81.

Quoting the famous naval hero John Paul Jones, Everitt likes to say, "I have not yet begun to fight." Jones ultimately prevailed during the Revolutionary War, and with luck, STEP might do the same. Perhaps it will be the experiment that finally finds a crack in the heart of Einstein's theory, one that could point us toward something even better: a new, all-encompassing theory of the universe. D

Steve Nadis*, a contributing editor to* Discover *and* Astronomy*, is co-author of* A History in Sum: 150 Years of Mathematics at Harvard*. He lives in Cambridge, Mass.*

A Ministep Into Space

While STEP remains grounded for lack of funds, a French mission called MICROSCOPE (MICRO-Satellite à traînée Compensée pour l'Observation du Principe d'Equivalence) is scheduled for launch in March 2016. Francis Everitt describes MICROSCOPE as "a room-temperature version of STEP" because it doesn't involve complex cryogenic technology. That should make MICROSCOPE less expensive than STEP but also about 1,000 times less precise. No one knows whether MICROSCOPE will be sensitive enough to detect violations of the equivalence principle. But being the first space-based test of that principle, "this mission … opens the way to even more ambitious ones," Pierre Touboul of the French space research center Onera wrote with his colleagues. —SN



The French MICROSCOPE mission will launch a small satellite into orbit, as in this artist's rendering, to test the equivalence principle.

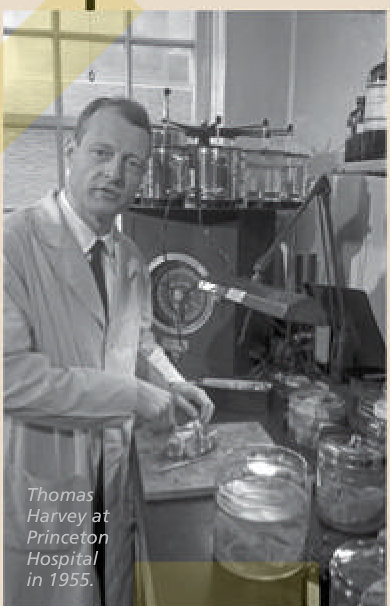
CNES/D. DUCROS

Between the Folds

For decades, people have probed Einstein's brain for clues to his genius. Some say it's time to give it a rest.

BY **JENNY BLAIR**

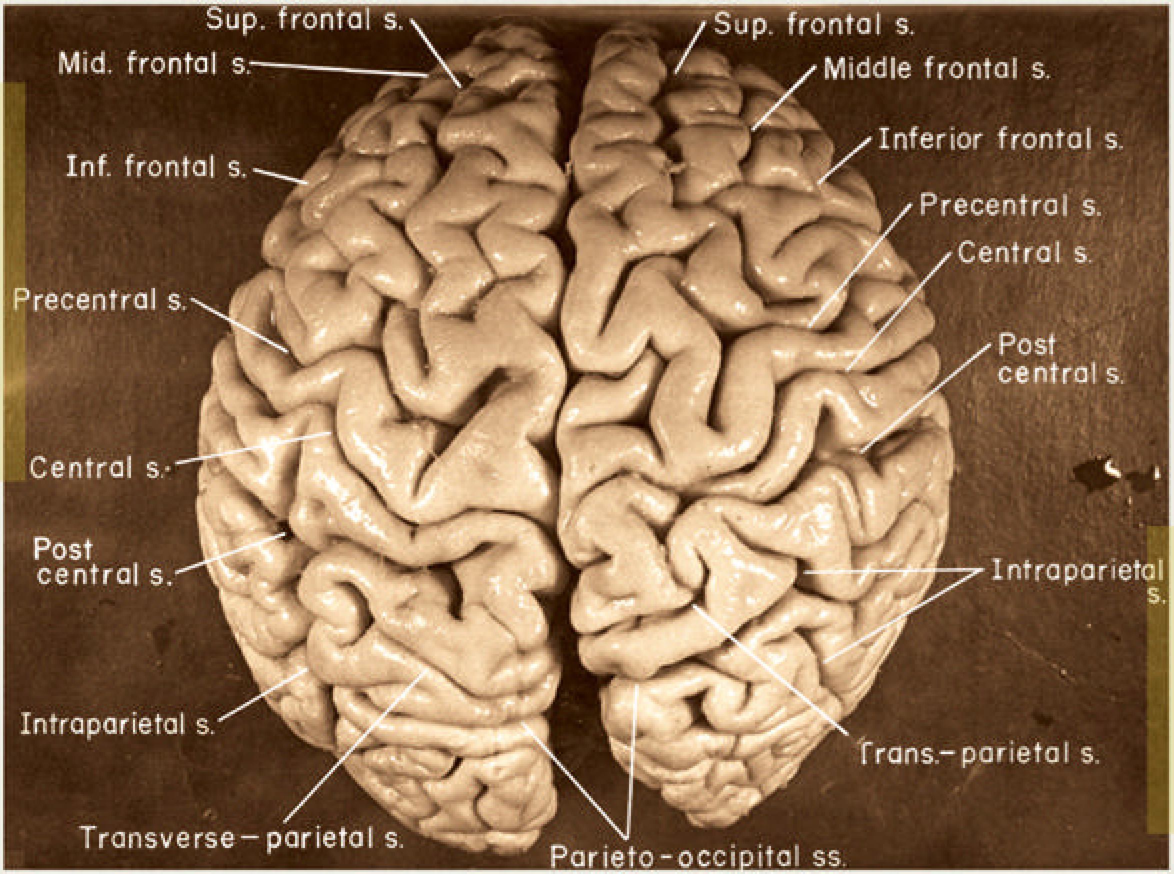
An elderly man pries open a jar and fishes out a dripping human cerebellum. He carves off a chunk with a kitchen knife and places it in a plastic pill bottle. Then, wiping a hand on his pants, the man hands the bottle to an admiring visitor.



Thomas Harvey at Princeton Hospital in 1955.

RALPH MORSE/THE LIFE PICTURE COLLECTION/GETTY IMAGES

The brain was Albert Einstein's. The man was Thomas Harvey, a pathologist who in 1955 removed, photographed and preserved the great physicist's brain during autopsy. In the decades since, the brain has enjoyed a certain celebrity. In the '80s, Harvey gave away slices to the curious, keeping the rest in a pair of glass cookie jars. (These bizarre transactions appear in the 1994 documentary *Relics: Einstein's Brain*.) In the late '90s, he carried it across the country in a Tupperware container to offer it to Einstein's granddaughter, who chose not to keep it. Finally, he gave it back to Princeton Hospital, where he performed the autopsy decades before.



Before Harvey partitioned Einstein's brain into 240 chunks, he photographed it from various angles. This is the top view.

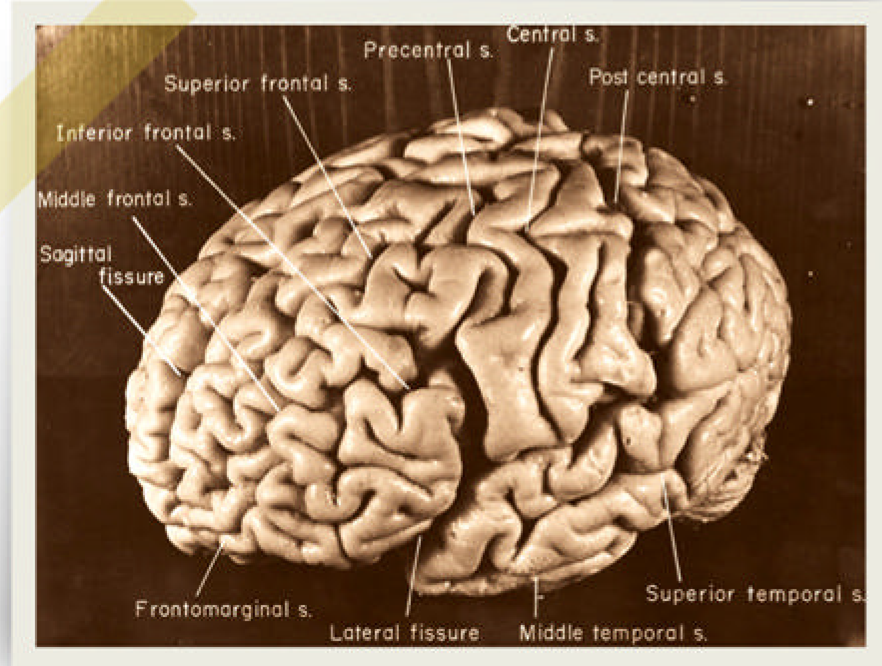
Ever since, researchers have pored over chunks, slides and photos of Einstein's brain, counting cells, measuring dimensions, describing shapes and comparing it with the brains of ordinary people. Every deviation from the purported norm became a potential explanation for Einstein's genius: his uncanny thought experiments, his kinesthetic imagination, his mathematical and musical abilities.

But some experts think it's all been a fool's errand — that the haphazard state of the specimen, wishful thinking by its explorers and our murky understanding of the mind-brain link render these conclusions questionable.

The hope that studying a postmortem brain will reveal secrets about its owner's mind is centuries old. The brains of Vladimir Lenin, Walt Whitman and mathematician Carl Friedrich Gauss were among the many removed for study. Nineteenth-century scientists fell into bitter debate as to whether intelligence lay in anatomy or whether a vital force — or even an immortal soul — was responsible for thoughts.

A philosophical divide persists to this day. Some researchers suggest this or that region of the brain corresponds to a mental faculty; others say it amounts to little more than phrenology, a 19th-century pseudoscience that claimed bumps on the skull could explain personality. The epithet dogs even some functional MRI studies, which seek to link specific thought processes to corresponding regions of the brain by measuring moment-to-moment differences in blood flow.

Those who would explore Einstein's brain are well aware they're treading potentially controversial ground. Nevertheless, they believe they're on to something. In 1985, neuroscientist Marian Diamond of the University of California, Berkeley, reported the Einstein brain had extra cells called glia.



These photographs show the left and right hemispheres of Einstein's brain, viewed from the side and swiveled slightly toward the viewer. Labels refer to the parts of the brain.

These cells support the "thinking" neurons in the left parietal lobe, an area above and behind the left ear involved in spatial relations and mathematics. She speculated that this "might reflect the enhanced use of this tissue in the expression of his unusual conceptual powers." Seven years later, a researcher in Osaka, Japan, suggested a link between that higher glia-to-neurons ratio and Einstein's purported dyslexia.

In 1999, neuroscientist Sandra Witelson reported an unusual configuration in the folds and grooves of Einstein's parietal lobes, suggesting they may have developed earlier in life than usual. She wondered if that configuration might have something to do with the physicist's skills in visual, spatial and mathematical thought. And Harvey himself co-authored a 1996 paper that suggested the brain's higher density of neurons might make for faster communication between them.

Most recently, a 2013 *Brain* paper by Florida State University anthropologist Dean Falk described the brain's surface. In examining Harvey's autopsy photographs and comparing the brain's appearance with 85 reference brains, she noted a number of intriguing features. For example, it had an omega sign, a knobby fold in the area of the brain that controls the left hand. This variant can be prominent in musicians who play stringed instruments. Einstein was an inveterate violinist.

From there it gets weirder. Part of the area controlling speech, called the Broca's area, was unusually convoluted, and areas controlling the facial muscles around the mouth were enlarged (a finding reminiscent of the photo of Einstein sticking out his tongue). Falk noted extra convolutions in the frontal lobes, which are believed to be involved in thought experiments. The right superior parietal lobe, which receives visual and spatial information, was large, too. Co-author Frederick Lepore wonders if the parietal lobes were the locus of Einstein's ability to envision space-time curvature.

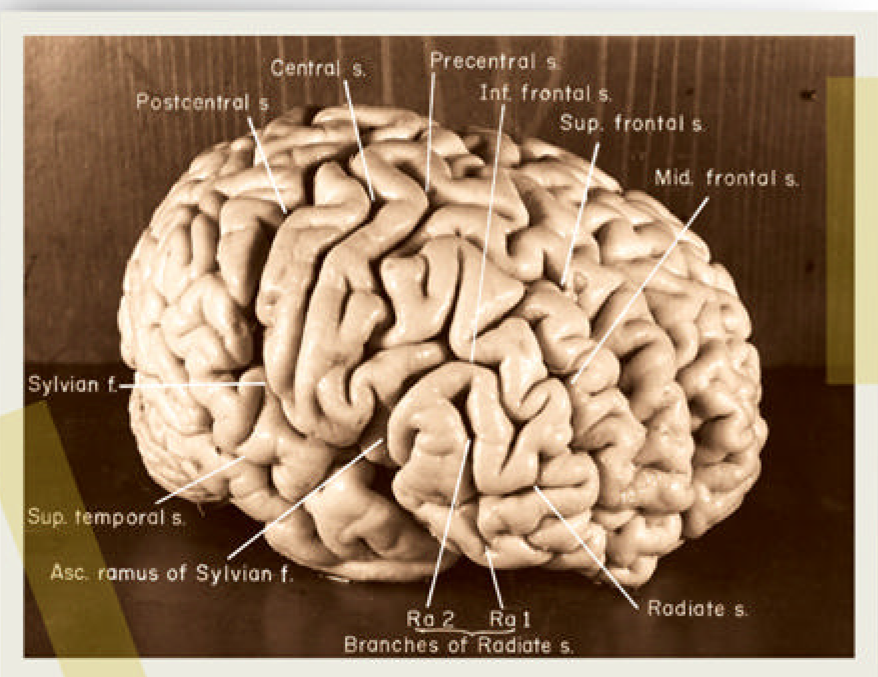
"But there's no way you could prove that, and we don't. We just say it's interesting," Lepore says. "The brain is different from the run-of-the-mill human brain, and it just happens to be that this guy was arguably the genius of our epoch."

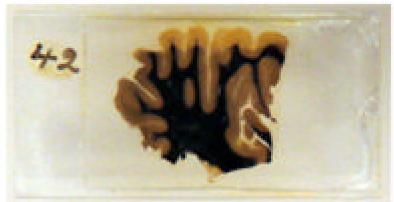
Exciting stuff, the researchers suggest. Stuff and nonsense, says Pace University psychology professor Terence Hines.

"If you start out with the preconception of 'This is the brain of somebody who's really smart,' you're going to be able to find something that confirms your bias," says Hines. Sloppy thinking pervades the Einstein's-brain literature, he says.

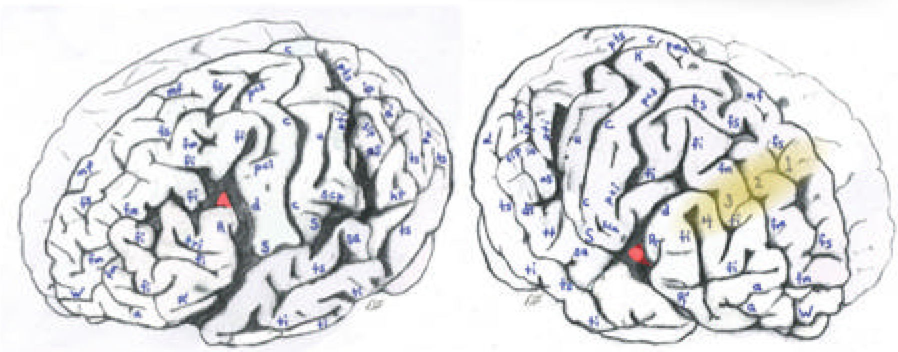
This spring, Hines published a scathing critique of nine Einstein's-brain studies in *Brain and Cognition*. Diamond's study on glia wasn't blinded, he pointed out. Higher neuron density has also been reported in schizophrenics, making Harvey's observation of dubious value. It's far from clear that Einstein had dyslexia. And Falk, Hines says, hasn't demonstrated that the unusual brain convolutions she found are due to anything but random variation.

Hines is not alone in his skepticism. Psychiatrist Lena Palaniyappan of the University of Nottingham sounds a note of caution about comparing different brains' convolutions. If you're analyzing brains from two different species, more





A slide with a sliver of the famed brain.



In a 2013 analysis of the photos above, anthropologist Dean Falk counted four ridges (numbered 1-4) — one more than usual — in the right frontal lobe, an area associated with abstract thought. Researchers disagree about the significance of such anomalies.

convolutions do mean more smarts. But, he notes, no one has demonstrated such a relationship when comparing human brains. So it's not clear what reports of extra convolutions in the Einstein brain really amount to.

Ann McKee, the Boston University neuropathologist who sounded the alarm about chronic traumatic encephalopathy in football players who have suffered concussions, says she's wary of studies purporting to ascribe mental function to structure alone. That's because structure tells only part of the story. Neural impulses race all over the brain, tying together both distant and adjacent structures moment by moment. Not taking those relationships between brain areas into account would be like trying to understand Manhattan's commerce by studying buildings but not traffic patterns.

These neural relationships are "so evanescent," McKee says, "and it's something that's only captured by studies of function, which are not possible from a postmortem exam."

Howard University physiology professor Mark Burke says the idiosyncratic way Harvey cut up the brain makes it hard to study, even with unbiased, state-of-the-art cell-counting techniques. He recalls his disappointing pilgrimage to the National Museum of Health and Medicine in Silver Spring, Md., where much of what's left of Einstein's brain now rests.

"I just kind of shook my head and said, 'Wow,'" Burke recalls. "It's a shame that it wasn't done systematically."

The brain, he says, is of "limited scientific value at this point."

But even if Einstein's brain were intact enough to be plumbed with the tools of modern science, we might have to remain agnostic about the source of his brilliance.

Harvard neurology professor Albert Galaburda believes that even if we could resurrect Einstein, we still would not be able to explain his mind. "[If] he has some differences, you can't tell that that's why he became a great physicist," he says. "Maybe it's because that's what doing physics does to your brain." D

***Jenny Blair** is a freelance writer in Michigan. Her last story for* Discover *was about fish that hide in open water.*

TOP RIGHT: CHRIS HELGREN/REUTERS/CORBIS

Researchers hunt for clues to a 3-million-year-old mystery on Ellesmere Island. Left to right: Travis Mitchell, Marisa Gilbert, Natalia Rybczynski and John Gosse.

Is our climate's future written in Arctic fossils from a warmer past?

COLD CASE

BY **KENDALL POWELL**

PHOTOGRAPHS BY **MARTIN LIPMAN**

On a warm Thursday in July, Natalia Rybczynski and I paddle our kayaks up the Gatineau River near Ottawa. Fluffy-topped, flat-bottomed clouds speckle the sky, and blooming cornflowers poke through old railroad tracks leading to a dock. We glide past a long-abandoned beaver lodge, its sticks cut at a distinctive angle and spilling helter-skelter down the riverbank into the bourbon-colored water.

Rybczynski (pronounced rib-CHIN-ski) is a big fan of beavers, Canada's official wildlife mascot; she's conducted research showing they gnaw sticks with just one front tooth at a time. But our 2013 outing to the river is a consolation trip. Normally she spends her Julys at a beaver pond site that's millions of years old and 800 miles north of the Arctic Circle, looking for clues about past global warming.

But this summer, Rybczynski, a paleobiologist, is confined to her home base, the Canadian Museum of Nature in Ottawa, as she recovers from a cross-country skiing accident that left her with a concussion. She'd much rather be wrapped in Gore-Tex, wavy brunette hair in a bandana, her dirt-ringed fingernails turning purple on the cold, dry tundra of Ellesmere Island.

Natalia Rybczynski awaits a radio call at the Beaver Pond site.

Today, Ellesmere, which lies next to Greenland on the eastern edge of Canada's Arctic Archipelago, supports only ankle-high tufts of cotton grass and mossy ground cover; the nearest tree is almost 1,200 miles south. But Rybczynski and her colleagues have unearthed evidence of a balmier Arctic from a slice of time referred to as the mid-Pliocene warm period, roughly 3 million to 3.3 million years ago. The island's treasure trove of fossils, preserved in permafrost, suggests the area was once an ancient boreal-like forest of larch, cedar and birch grazed by miniature beavers, three-toed horses and black bear ancestors.

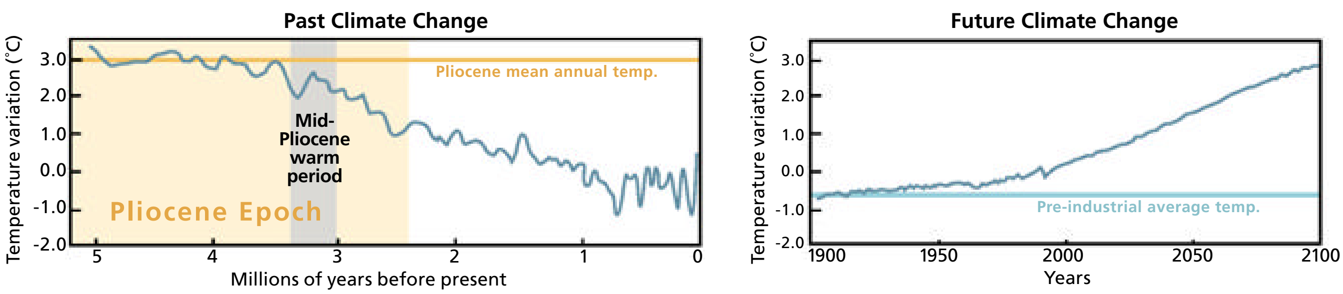
The fossils act as a transcript that can be parsed for indicators not only of past climate, but also the climate of the future, making the team's work as important to climate modelers as it is to paleobiologists.

Monitoring data show that the Arctic has already heated up more dramatically than the rest of the planet. While Earth's landmass has warmed by about 1 degree Celsius (about 2 degrees Fahrenheit) over the past century, on average, land temperatures in the Arctic have risen almost 2 C (3.6 F). But to date, when climate modelers try to project *future* warming for the Arctic, the numbers are lower than expected; for reasons not yet fully understood, they don't reflect the region's accelerating warming. That means current climate models for the Arctic cannot accurately project the region's future. If projections are too shaky to tell us what to expect as Earth warms up, the only alternative, Rybczynski points out, is "waiting 100 years to see what happens."

Helpfully, during the mid-Pliocene warm spell, Earth had the same concentrations of carbon dioxide in the atmosphere and the same average 2 to 3 C (3.6 to 5.4 F) rise in global temperatures we're headed toward. With its uncanny resemblance to our impending new normal, the mid-Pliocene warm period offers an invaluable proxy for modelers charting future warming, says James White, director of the Institute of Arctic and Alpine Research in Boulder, Colo. "Sometimes the Earth hands you a favor, and this is one."

While today's carbon dioxide levels — approaching a global average of about 400 parts per million — are largely due to people burning fossil fuels, the physical factors that directed the climate system 3 million years ago behave the same way today. The Ellesmere fossils are pieces of "ground truth" that can plug the holes in simulations of future climate change. The more we know about what changes to expect — and how fast they'll come — the better we can prepare.

"We're trying to understand how what we're doing to the Earth's atmosphere and oceans will play out in the future," says Bette Otto-Bliesner, who runs a full-complexity climate model — and its 1.5 million lines of code — through a



Left: During much of the past 5 million years, Earth's climate was in a cooling trend (estimated here from studies of ancient marine fossils). But during the mid-Pliocene, the planet warmed by 2 to 3 degrees Celsius — the same rise we're headed toward. Right: Over the past century, global average temperatures have increased, and scientists project a global average rise of 3 degrees Celsius by the end of this century.

TOP: MARTIN LIPMAN. BOTTOM: ALISON MACKEY/DISCOVER AFTER ASHLEY BALLANTYNE AND D.J. LUNT, ET AL., [PHILOSOPHICAL TRANSACTIONS A], (DOI: 10.1098/RSTA.2013.0146) 2013

Ellesmere Island's Grise Fiord, whose Inuit name means "the place that never thaws out."

supercomputer named Yellowstone at the National Center for Atmospheric Research in Boulder. "How much we trust our model depends on how well we can reproduce the climate of yesterday. In this case, yesterday is the Pliocene."

Rybczynski and her team have their work cut out for them. Capturing the full picture of the mid-Pliocene's doppelganger climate requires reconstructing the whole Arctic paleoenvironment from sparse bits of remains. That means cataloging everything from the creatures and vegetation that co-existed to the rainfall and forest fire patterns. It means tracking landscape shifts and the swirl of ocean currents, and conjuring the ghost of Pliocene sea ice.

Piecing together a climate from a smattering of fossils is the ultimate forensic work. But this case, Rybczynski knows, is critically important to solve — and time is not on her side.

While the worst consequences of climate change are still to come, evidence of amplified warming already abounds in the Arctic. At a hamlet on the southern end of Ellesmere called Grise Fiord, whose Inuit name means "the place that never thaws out," the Inuit have watched the sea ice that supports their traditional seal, polar bear and whale hunting decrease every year. The Intergovernmental Panel on Climate Change has warned it's likely that the Arctic will be sea ice-free in summertime before 2050.

MONITORING DATA SHOW THE ARCTIC HAS ALREADY HEATED UP MORE DRAMATICALLY THAN THE REST OF THE PLANET.

"The changes to the Arctic represent the single most important natural history event of our lifetime," says Meg Beckel, CEO of the Canadian Museum of Nature, which helps support the team's $80,000 polar expeditions. "It's dramatic. What *will* it look like 100 years from now?"

REANIMATING THE PAST

Rybczynski's love affair with Arctic fossils began when she was a high school student in the late 1980s, learning about paleobiology from her mentor, C. Richard "Dick" Harington. But it wasn't until she graduated from college in 1994 that she joined Harington — the museum's curator of Quaternary zoology at the time — on a research expedition to Ellesmere Island. Two years earlier, he made a startling discovery at the island's Beaver Pond site. Geologist John Fyles, who discovered the site, had shown Harington beaver-cut sticks from Ellesmere — a clear indication that the spot was once home to something other than polar bears — and Harington wanted to see the site for himself.

On that first trip, on an outcrop a few hundred yards from the mouth of Strathcona Fiord, he immediately picked up three bones lying on the surface.

One was from a small beaver and another from a bear. The abundant beaver skeletons were *Dipoides*, a species two-thirds the size of modern beavers that had been found at sites in China and Idaho dated to the Pliocene. The site gave up more beaver-chewed sticks and saplings. That, plus the diversity of other wildlife found — frogs, fish, deerlets, hares — led Harington to conclude that around 3 million to 4 million years ago, the site was a beaver-dammed watering hole.

At the time, it was a rather radical idea. "People see the Arctic as an ancient landscape that's been that way forever," says Rybczynski. But Harington was suggesting "right up until the last ice age, you had a forest and this great diversity of mammals, and a frog and fish and everything!" The fossil evidence was hard to ignore. It seemed to hail from the rough stretch of time that included the mid-Pliocene warming event. But they weren't entirely sure.

By the early 2000s, Rybczynski was at Duke University, studying beaver evolution for her dissertation. But her mind kept returning to the high Arctic. Were she and Harington reading those bones properly? Were they really from the mid-Pliocene? A forest, she knew, would require more than a couple of degrees of warmth to thrive. Just how high did the thermostat rise?

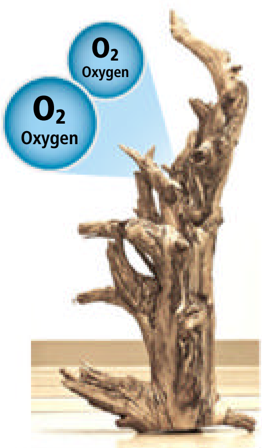
RONALD CAMPBELL


The research team's 2008 camp at the Fyles Leaf Bed site near Strathcona Fiord on Ellesmere Island, in the Canadian Arctic.

To figure out those answers, Rybczynski turned to Ash Ballantyne, another grad student at Duke, who was using oxygen isotopes from tree cores to determine historical temperatures. Meeting him at his lab bench one day, she handed him a small disc of larch tree trunk with about 20 growth rings. "Cool specimen," Ballantyne recalls thinking, but not remarkable. "Then she told me it was maybe 3.5 million years old and asked, could I possibly extract some climate information out of this?"

Judging by the wood's apparent freshness, Ballantyne thought so. It still had bark on it. The natural deep-freeze of Ellesmere's permafrost had mummified the wood. That meant Ballantyne could isolate cellulose, a structural molecule that keeps a record of temperatures in the plant's lifetime. The ratio of two oxygen isotopes in the larch's cellulose would give Ballantyne a temperature range.

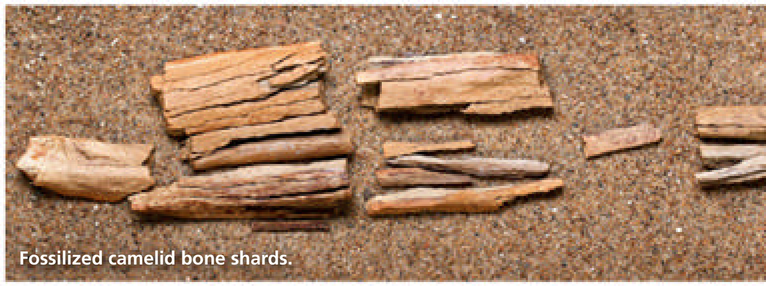
He calculated that the Beaver Pond larch thrived at a yearly average of minus 5.5 C (22 F), about 14 degrees warmer than today's average. "It was warmer than previous estimates [for the mid-Pliocene Arctic], but it seemed to make more sense," says Ballantyne, now a climate scientist at University of Montana in Missoula.



Oxygen isotopes in ancient tree bark revealed that temperatures during the mid-Pliocene were warmer than believed.

For a productive forest to grow, Ballantyne explains, temperatures have to remain above freezing for half the year. "We intuitively knew this," he says, and the larch data confirmed it.

Rybczynski and Ballantyne realized the larch might have lived through a period of increased Arctic warmth similar to the one we're heading into, and it could also hold clues about what else was happening on the globe — if the larch really was from the mid-Pliocene. Rybczynski realized the team needed stronger evidence that the sites were indeed Pliocene, including any more fragments the permafrost might give up.


Fossilized camelid bone shards.

A SHOCKER IN THE SHARDS

In 2003, Rybczynski returned to Ottawa, essentially taking over for Harington at the museum when he semi-retired. With support from the museum, her team revisited Ellesmere in 2006, working in an area just 6 miles south of the Beaver Pond site, called the Fyles Leaf Bed.

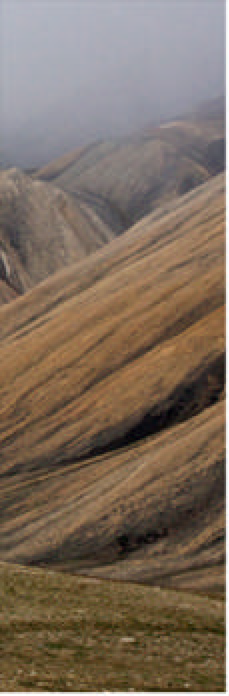
The three-person team crouched on the steep ridge, scouring layers of sandy gravel and leaf litter. On the last day, following her own motto — "Pick up everything!" — Rybczynski plucked a fragment from the dirt that looked like either bone or mummified wood. She wrapped it in toilet paper and hiked it back to camp. Sitting at the kitchen tent table, she confirmed the shard was, indeed, bone.

Encouraged by that find, the team returned two summers later and turned up a few more slivers — enough to start piecing them together in the kitchen tent like the family jigsaw puzzle. Rybczynski could tell she had the entire thickness of the bone, from the outer surface to the hollow. That anatomical measurement, cortical bone thickness, scales with overall body size.

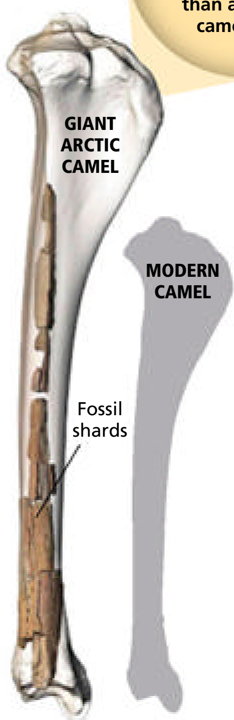
Whatever this thing was, it was huge.

When Rybczynski returned to the lab and sawed a tiny slice off the end of one shard, she caught the faintest unmistakable whiff of singed flesh. "Ooh, that's collagen,"

FROM TOP: MARTIN LIPMAN (2); LEE NARRAWAY



By piecing together the bone shards from the Fyles Leaf Bed site, Rybczynski was able to identify the animal they once belonged to: a camelid that lived in a boreal-like forest during the mid-Pliocene, shown above in an artist's rendering.



she recalls thinking. "That's *really* interesting."

Like DNA, collagen holds a sequence that might help reveal an animal's identity. Rybczynski hoped she could place another creature among the larch needles and cones on the forest floor. "This had the possibility of being different than anything we knew [from the Beaver Pond site], even bigger than the bear," she says. "Of course, I was kind of curious."

The following year, in 2009, Rybczynski met just the right person to unlock the answer. Michael Buckley had perfected a new collagen fingerprinting technique to identify fossils. Rybczynski asked if it would work on her mystery beast. Collagen probably could survive in the high Arctic for a few million years, he said, but no one had successfully tested anything that old.

Rybczynski sent samples to Buckley's University of Manchester lab in the U.K. When he compared the collagen readout with 32 species he'd already sequenced, Buckley saw it aligned most closely with a group not typically associated with the Arctic.

He emailed Rybczynski: "It looks like a camelid. Is that good?"

"Good? It is incredible!" came her reply.

Rybczynski knew this family, which includes camels, llamas and alpacas, had evolved in North America before spreading to South America, Asia and eventually Africa. But this animal lived 745 miles farther north than any of its previously found relatives. They might have discovered the first forest-roaming camel.

To be certain, in 2010 she headed back to the Fyles Leaf Bed once more in search of more bone. This time, the expedition team recovered more shards — bringing the total to 30 — which yielded some anatomical clues. In analyzing the shards, Rybczynski realized they made up a single tibia from a giant camel about 30 percent larger than its modern cousins.

The 9-foot-tall camel might have sideways-chewed birch leaves, its splayed feet lumbering over snow in half a year of darkness and half a year of midnight sun. It's an odd image for most of us, but to Rybczynski, it's more evidence that in the past the Arctic was warmer and tree-filled and had more biodiversity.

"If you were casually walking through" that past Arctic, Rybczynski says, "it would have the feel of a boreal forest with a few differences — including a camel."

A PINPOINT IN TIME

Rybczynski had used every scrap of inference and cutting-edge technology to pull the camel's identity out of those sad-looking shards. Yet she still couldn't be sure it was from the *mid*-Pliocene. Although the Ellesmere fossils matched other specimens from the Pliocene Epoch, it's a span of about 3 million years. Without a more precise date, it would be impossible to construct a meaningful climate story from the fossils.

A region's climate rests on many variables: land and sea temperatures, the shape of the

TOP: JULIUS CSOTONYI/CANADIAN MUSEUM OF NATURE. BOTTOM: ALEX TIRABASSO/CANADIAN MUSEUM OF NATURE, ADAPTED BY PERMISSION FROM MACMILLAN PUBLISHERS LTD [NATURE COMMUNICATIONS], (DOI: 10.1038/NCOMMS2516) 2013

During the mid-Pliocene, boreal-like forests similar to this one in Siberia stretched across the high Arctic.

landmass, how ocean currents mix globally, even the trajectory of Earth's orbit. Being off by even a million years — a blink in geologic time — could dramatically change those factors. The team needed a narrower window.

To get that time stamp, Rybczynski sought the help of geologist John Gosse at Dalhousie University in Nova Scotia. He had refined a dating technique that could reliably clock sand as old as 8 million years, and she hoped he could extract some exactness from the Ellesmere sands. But Gosse had his doubts about the site's age.

"Skeptical? I definitely was," he recalls. In his mind, the site snuggled too closely to glacial deposits from the last ice age that lay atop the sloping Martian-esque hills. That would make it merely 35,000 years old. And, he says, the site was sandy, "like your favorite beach" with none of the compaction typical of sites millions of years old.

Gosse carefully tunneled into the hillside below the camel bone find and extricated a 2-kilogram (4.5-pound) chunk of sand. When he got it to his laboratory, Gosse isolated the quartz from the sample and then chemically squeezed out traces of aluminum-26 and beryllium-10 isotopes. The aluminum decays twice as fast as the beryllium; the longer sands are buried, the lower their ratio will be.

The samples' ratios told him the camel roamed 3.8 million years ago and the beavers set up their dam 3.4 million years ago, give or take half a million years — age ranges accurate enough to place them in the middle of the mid-Pliocene warm period.

"The age was right on what Dick Harington had predicted," says Gosse. "I was extremely relieved to know we had an independent way of verifying it. I'm glad I didn't bet them."

At the same time, Ballantyne and Rybczynski gathered collaborators who knew multiple ways to nail down past temperatures, calculating proxies from plant and soil bacteria fossils. Three distinct data sets pointed to the same number: an average yearly temperature 34 F warmer than today's Arctic.

Such an average would have extended the above-freezing growing season from May to September. The Pliocene animals, plants and microbes all told the same story: They lived in a boreal-like forest ecosystem not quite like any that exists today. (The nearest modern example would be the Eastern Siberian taiga, dominated by larch and home to elk, weasels and wolverines.)

While average global temperatures in the mid-Pliocene rose only 3.6 to 5.4 F, the Arctic was a totally different world. "So the question is, what was amplifying temperatures in the Arctic?" Ballantyne asks.

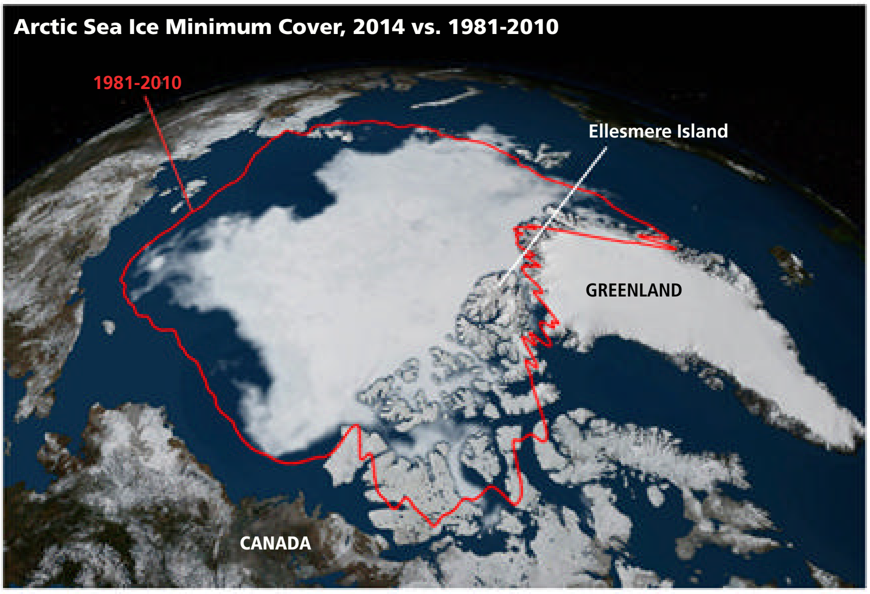
His best guess is that sea ice, or rather the lack of it, played a big role, thanks to something called the albedo effect. Shining white sea ice reflects most of the sun's energy back into space. Where it's absent, the dark ocean waters absorb 90 percent of the energy coming in, heating it up. That warmth ultimately limits the reforming of sea ice and also has a warming influence on nearby land.

Ballantyne's next challenge is to sleuth out the mechanisms that accelerated Pliocene sea ice melting.

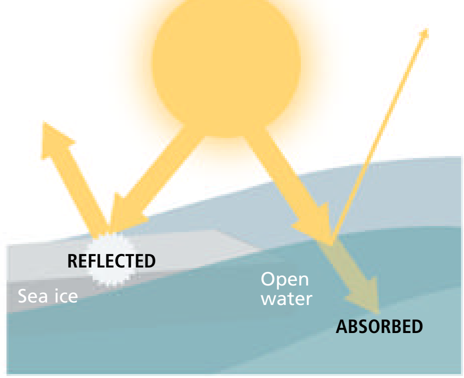
Sand unearthed beneath the camel bone find was **chemically dated** to an age of about 3.8 million years.

Geologist John Gosse collects sand samples from the lower levels of the Fyles Leaf Bed site on Ellesmere Island.

TOP: KONSTANTIN MIKHAILOV/NATURE PICTURE LIBRARY. BOTTOM: MARTIN LIPMAN



Ice-Albedo Effect



Left: This satellite image from September 2014 shows Arctic sea ice at its annual minimum of about 2 million square miles — about 480,000 square miles less than the 1981-2010 average (outlined in red). Top: In the ice-albedo effect, ice reflects solar energy; open water absorbs it. Less ice means warmer oceans, hindering ice formation.

LEFT: NASA/GODDARD SCIENTIFIC VISUALIZATION STUDIO. RIGHT: ALISON MACKEY/DISCOVER

It won't be easy, Ballantyne says. Past sea ice tends to leave even fewer traces than giant camels. But an intriguing new study suggests he's on the right track. In the summer of 2013, Ballantyne and his former adviser, White at the Institute of Arctic and Alpine Research, ran a "what if" experiment.

"Well, hell, let's just take the ice away and see what happens," White recalls the team thinking. They ran a Pliocene climate model with all ice removed from the Arctic year-round. Unlike previous Pliocene models, this "no ice" version returned temperatures 18 to 27 F warmer than today's average annual temperatures for the Canadian Arctic and Greenland, coming closer to what the historical data pulled from the ground said.

THE RESEARCHERS MUST RESOLVE THE MISMATCH BETWEEN THE PLIOCENE MODELS AND REALITY.

The researchers must resolve the mismatch between the Pliocene models and reality. "It's a key question for the future," says White, "because we are headed for a Pliocene climate."

TURNING BACK TO THE FUTURE

While Rybczynski recuperated in Ottawa in 2013, Gosse and the expedition team continued the hunt for puzzle pieces, this time traveling to westernmost Banks Island to search for Pliocene dwellers and date sites there.

The team brought back enough bones to fill two cupped hands and several buckets of sands for dating. They think one bone might be from another camel, but it's not yet clear whether it dates to the Pliocene or the more recent ice age. These hard-won bits may not seem impressive to an outside observer. But, as Gosse explains, each one provides a data point for a condition happening locally that can be tied to the global record.

Once his team places all the sites across the high Arctic in time, then all the rich data — the field notes, the fossils, the lists of insects and vegetation — can help climate modelers fix their big problem. They'll have a detailed picture of the mid-Pliocene paleoclimate. And then, they can solve for X to find the climate conditions that created that warmth, much like the no-ice experiment.

"We're constantly developing the model to make it better and better," says Otto-Bliesner. She and Ballantyne next want to include how ash from forest fires affected Pliocene climate. Rybczynski's sites could hold the answer.

She's been itching to return to the Fyles Leaf Bed, where the charcoal-black layers of leaf litter represent annual cycles spanning thousands of years. Hidden among them is the tale of how vegetation and wildfire seasons changed with temperature.

Time seems to be speeding up for Rybczynski and the others trying to solve this climate puzzle. On May 9, 2013, the Mauna Loa observatory in Hawaii recorded carbon dioxide levels climbing above 400 ppm for the first time. We are steadily marching toward a global yearly average above that threshold — and a Pliocene climate. The future is starting to look a lot like the past; only this time, 7 billion people will feel the heat.

And that includes Rybczynski. Thawing permafrost in the Arctic both dismays and delights her. Slumping hillsides leave slashes of broken-open earth, revealing new excavation sites. But the thaw could also spell the end for Ellesmere's exquisitely preserved fossils.

"That is the double-edged sword. We might lose the Beaver Pond site, but we find these new sites," says Rybczynski. "It definitely gives me a sense of urgency — getting this work done and getting it right." D

__Kendall Powell__ is a freelance science writer and editor who writes about everything in the realm of biology, from molecules to maternity.

Subscribers can see more climate graphics related to this story at **DiscoverMagazine.com/ArcticFossils**

WAKE-UP CALL

Getting a good night's sleep is more than a luxury — it's a matter of life and death.

BY **KENNETH MILLER**
ILLUSTRATION **BY MATT MANLEY**

At first, no one noticed that Joe Borelli was losing his mind — no one, that is, but Borelli himself. The trim, dark-haired radiologist was 43 years old. He ran two practices, was an assistant professor at the Medical University of South Carolina and played a ferocious game of tennis. Yet he began to have trouble recalling friends' names, forgot to run important errands and got lost driving in his own neighborhood. He'd doze off over paperwork and awaken with drool dampening his lab coat.

Borelli feared he had a neurodegenerative disease, perhaps early onset Alzheimer's. But as a physician, he knew that memory loss coupled with fatigue could also indicate obstructive sleep apnea (OSA), a disorder in which sagging tissue periodically blocks the upper airway during slumber. The sufferer stops breathing for seconds or minutes, until the brain's alarm centers rouse him enough to tighten throat muscles. Although the cycle may repeat hundreds of times a night, the patient is usually unaware of any disturbance.

Borelli checked in to a sleep clinic for tests, which came out negative. He went to a neurologist, who found nothing wrong. At another sleep clinic, Borelli was diagnosed with borderline OSA; the doctor prescribed a CPAP (continuous positive airway pressure) machine, designed to keep his airway open by gently inflating it. But he still awoke feeling exhausted, and he quit using the device after a couple of months.

Borelli's fingers soon grew so clumsy that he couldn't button his shirt cuffs. He was easily winded, and his heart raced whenever he rose from a chair. He developed chronic severe anxiety. He gave up tennis and his chairmanship of a national professional committee. His marriage fell apart. He contemplated suicide. "One day," he recalls, "I collapsed in the shower, crying." Then he went looking for the best sleep specialist in America.

He settled on Christian Guilleminault, a venerated clinician and researcher at Stanford Medical School, who diagnosed him with upper-airway resistance syndrome (UARS), a condition in which the airway is partially obstructed during sleep. Unlike full-blown apnea, UARS — which is much harder to detect — restricts breathing rather than stopping it. But both conditions, which prevent a person from sleeping deeply for any length of time, can trigger ailments ranging from cognitive deficits to hypertension.

"You've had this your entire life," Guilleminault declared before putting Borelli back on a CPAP at more than twice the air pressure as before.

Borelli hoped desperately that Guilleminault could cure him. Getting a good night's sleep had become a matter of life and death.

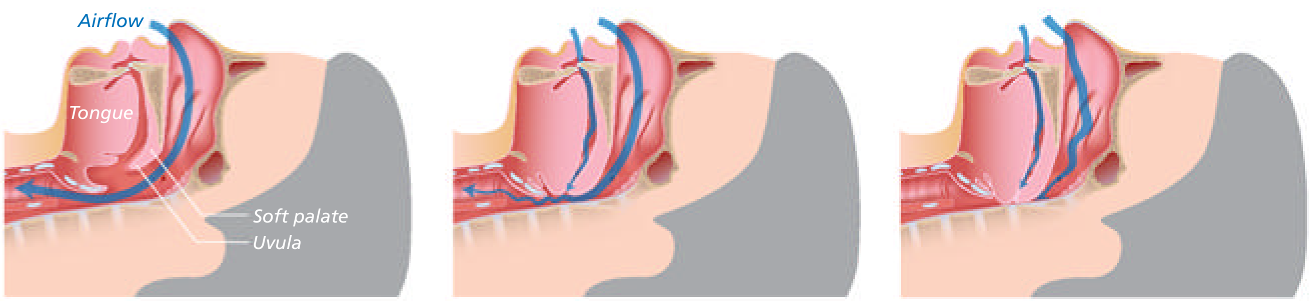
A NATIONAL SLEEP CRISIS

The first sleep-research lab opened in 1925 at the University of Chicago. Yet until fairly recently, scientists focused more on describing the phenomenon — its stages, aberrations and basic physiology — than on understanding its purpose. No one could really say what sleep was for, or even whether it was absolutely necessary.

Over the past couple of decades, however, researchers have been closing in on the whys of sleep, largely by studying what happens when organisms are deprived of it. A growing stack of evidence suggests that sleep is central to the health of both body and mind, regulating processes ranging from memory to metabolism.

These findings take on added urgency because we're experiencing a national sleep crisis. According to the National Institutes of Health, up to 70 million Americans have a serious sleep disorder — including chronic insomnia as well as sleep apnea and other physiological problems — though many go undiagnosed. The Centers for Disease Control and Prevention reports that 37 percent of us get less than seven hours a night, generally considered the tipping point for health problems. Nearly 20 percent of us work shifts with schedules that throw sleep cycles off kilter.

"We've become a 24/7 culture," says retired Cornell psychologist James B. Maas, who helped found the field of sleep education back when TV stations signed off at midnight. "We have to learn to value sleep."



NORMAL BREATHING | PARTIAL OBSTRUCTION | COMPLETE OBSTRUCTION

Uninterrupted breathing is crucial for restorative sleep, but the airflow in individuals with obstructive sleep apnea can be completely cut off by soft tissue in the mouth and throat. Harder to diagnose but often as debilitating, upper-airway resistance syndrome is a partial obstruction of the airway.

SHUTTERSTOCK/ALILA MEDICAL MEDIA

Joe Borelli, at home with a CPAP machine that helps him breathe, experienced years of fatigue and cognitive impairment due to an undiagnosed sleep disorder. Now healthy, he has created the SleepMapper app to help other CPAP users monitor the quality of their sleep.

SEAN RAYFORD

The struggle to understand sleep apnea and related conditions, known collectively as sleep-disordered breathing, is a major battlefront in the current sleep-science revolution. A seminal moment came in 1998, when pediatric pulmonologist and sleep specialist David Gozal published a study showing that children with OSA were at greater risk of having trouble learning.

Gozal, then director of sleep medicine at Tulane University, took 297 New Orleans first-graders who were performing poorly at school and screened them for apnea. Eighteen percent tested positive — about six times the normal rate. The tonsils and adenoids of 24 of those students were removed, the standard treatment for sleep apnea in children. The parents of the other 30 declined the surgery. Among the treated students, average grades rose significantly the following year, while the untreated kids, along with a control group without OSA, showed no academic improvement.

"I have 24 nice letters from parents thanking me," says Gozal, who's now at the University of Chicago Medical Center.

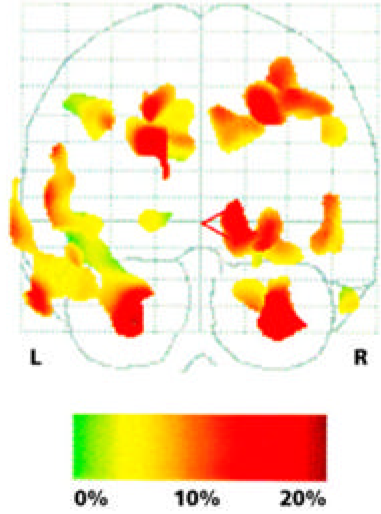
OSA was already thought to be associated with high blood pressure in adults, though the reasons were unclear. Gozal wondered if the same mechanisms might also be driving the correlation between OSA and learning difficulties. As a first step toward finding out, he subjected sleeping rats to bouts of hypoxia, or partial oxygen deprivation, that mimicked apnea episodes. EEG readings showed patterns of sleep disruption similar to those of human OSA sufferers. Afterward, the animals had trouble navigating a water maze. Tissue analysis showed they'd lost neurons in brain regions associated with learning and memory.

In the early 2000s, researchers led by UCLA neurobiologist Ronald M. Harper detected brain-cell death and white matter injury in adult humans with OSA, in areas controlling not only cognitive functions but also mood, breathing, blood pressure and the nervous system's ability to coordinate sensory information and movement. Meanwhile, Gozal's team discovered that rats with simulated OSA, and

Over the past couple of decades, researchers have been closing in on the whys of sleep, largely by studying what happens when organisms are deprived of it.

children with the actual disorder, had elevated levels of inflammation markers that can presage cardiovascular problems. In a landmark 2007 study, they performed tonsillectomies on 26 kids with OSA who showed signs of vascular dysfunction; after the operations cured their sleep apnea, arterial tissue returned to normal in 20 of the patients.

Gozal's team eventually found that children with OSA who also had specific gene variants were at particularly high risk for cognitive, cardiovascular or metabolic side effects. And in 2012, they uncovered the first evidence that sleep apnea influences epigenetics, altering gene expression without changing an individual's DNA. In one kind of epigenetic change, known as DNA methylation, a methyl group (a carbon atom plus three hydrogen atoms) is added to a portion of DNA; it essentially flips a gene's switch to the "off" position, shutting down the often-crucial function it performs. In children with OSA and elevated inflammation levels, at least one immune-system gene tends to be highly methylated.



Compared with the brains of normal sleepers, participants with obstructive sleep apnea had reductions in gray matter of up to 18 percent in several regions, according to a 2002 study.

Hypermethylation can promote tumor growth; that may explain why, in a separate study, Spanish researchers in 2012 found higher rates of cancer among adult sleep apnea patients.

Although the damage caused by OSA comes partly from sharp fluctuations in oxygen levels as the patient fights for breath, much of the disorder's devastation appears to result from its disruption of sleep. "We've separated those elements," says Gozal. "Fragmented sleep alone is associated with inflammatory processes, oxidative stress and a variety of downstream consequences."

Sleep doesn't just allow the body to focus on rebalancing hormone levels and hunting down pathogens. It also enables the brain to do some crucial housecleaning — cognitive and otherwise.

DEALING WITH DEFICIT

Not all sleep deprivation, of course, is caused by disorders such as apnea. Many of us simply go to bed too late or have trouble falling asleep once we get there — a pattern we may repeat night after night. In 1999, University of Chicago endocrinologist Eve Van Cauter published the first study of the metabolic effects of that kind of chronic sleep deficit. At her lab, she restricted 11 healthy young men to four hours of sleep for six nights. For days afterward, the subjects metabolized glucose as poorly as pre-diabetics. Their blood cortisol, a hormone that rises with both stress and aging, reached levels common in much older men.

In later studies, Van Cauter and her colleagues found that men with a sleep debt developed higher levels of the hormone ghrelin, which stimulates the appetite, and lower levels of leptin, which suppresses it. Testosterone levels dropped as well. Such endocrine changes may help explain why epidemiologists have found elevated rates of obesity and diabetes among habitual short sleepers. "An animal will only deprive itself of sleep if it needs more time to forage," Van Cauter observes. "So the body interprets sleep deprivation as a need to find more food." In response, our hormones spur us to seek out edibles and store energy as fat.

As it sends the nervous system into emergency mode, sleep deprivation does other kinds of damage. It can trigger widespread inflammation, which is the immune system's response to a generalized threat, even as it decreases that same immune system's ability to target specific viruses. As a result, sleep-deprived people have been shown to respond less robustly to vaccinations and to catch more colds. Inflammation also erodes telomeres, the "caps" at the ends of chromosomes that protect

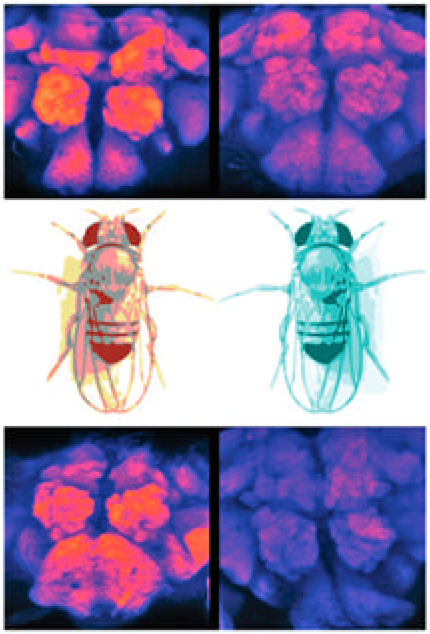
Eve Van Cauter, director of the Sleep, Metabolism and Health Center in the Department of Medicine at the University of Chicago, leaves a sleep study lab after meeting with a participant.

genes from degradation, which can lead to early cell death, premature aging and even cancer. Several recent studies report that telomeres are shorter among undersleepers. The risk of depression — another disorder associated with inflammation — is 16 times greater after a year of insufficient sleep, according to a 2013 study by UCLA psychoimmunologist Michael Irwin.

Sleep doesn't just allow the body to focus on rebalancing hormone levels and hunting down pathogens. It also enables the brain to do some crucial housecleaning — cognitive and otherwise. Many experiments have shown that when people or animals learn a skill, they perform it better after a good sleep. Some of this memory consolidation may occur through dreaming. For example, EEGs indicate that sleeping rats replay the running of a maze in a brain region devoted to spatial learning. But the brain during sleep also appears to erase some memories to preserve others. How this might work was first sketched out in 2003 by University of Wisconsin psychiatrist and neurobiologist Giulio Tononi. He theorized that the brain becomes overloaded with new neuronal connections — or synapses — during waking hours, as an animal absorbs information. To prune excess connections, the sleeping brain weakens each synapse by a proportional amount so that only the strongest survive, Tononi suggested.

His hypothesis was confirmed in an experiment conducted by Paul Shaw, a neurobiologist at Washington University in St. Louis. Shaw exposed fruit flies to an environment rich in social interaction and counted their synapses before and after; as expected, the flies grew lots of new connections. Then he let them sleep for as long as they wanted, which proved to be longer than usual, suggesting that they needed time to consolidate what they'd learned. When the flies awoke, Shaw found, the number of synapses was greatly reduced, just as Tononi would have predicted.

University of Rochester neuroscientist Maiken Nedergaard recently revealed another way the brain tidies up during sleep. In a 2012



Synaptic connections (shown from different angles, top and bottom) developed during a fruit fly's waking hours (left) were pared down after sleep (right), confirming that the brain does some housecleaning during slumber to keep only the most useful connections.

paper, Nedergaard and her colleagues announced the discovery of a waste-disposal system in the brain, in which toxic metabolites such as beta amyloid — associated with Alzheimer's and other neurodegenerative diseases — are flushed out by cerebrospinal fluid with the help of support cells called glia. In 2013, the team released a mouse study showing that this system turns on during sleep.

"It's been known for years that diseases like Alzheimer's are associated with sleep disturbances," Nedergaard says. "But maybe physicians should be treating sleep to slow the progression of the disease." Indeed, she notes, a 2009 study at Washington University found that sleep-deprived mice developed Alzheimer's-like brain plaques more often than their well-rested cousins. "Because it fits, right? If you don't sleep, you don't clean your brain."

Joe Borelli is evidence of that assertion.

Within months of beginning his second round of CPAP treatment in 2009, Borelli was feeling more rested than he had in ages. The symptoms that dogged him for five years — the memory lapses, anxiety, clumsiness, heart palpitations and all the rest — began to vanish. So did his high blood pressure.

Borelli, 53, went on to create an app, known as SleepMapper, to help other CPAP users optimize their therapy. And although his mental acuity isn't quite what it was before years of cumulative damage from his sleep disorder, he's not complaining. "I lost 50 percent of my brain to this disease," he says, "but I got 90 percent back. I'm a happy, happy camper." D

Kenneth Miller *is a Los Angeles freelance writer who contributes frequently to* Discover.

Before diagnosis and treatment, Borelli was forced to give up many of his professional and personal interests because of the health problems caused by upper-airway resistance syndrome. But now he's back in the game, shown here during practice at a South Carolina tennis club.

TOP: CHIARA CIRELLI. BOTTOM: SEAN RAYFORD

Our First Winter

Fossils are just one piece of the puzzle at the oldest hominid site outside Africa. Will it rewrite human evolution?

BY **GEMMA TARLACH**

They were small, the tallest barely more than 5 feet. Their bodies were essentially the same as modern humans — from the neck down. Their skulls were another matter, with braincases less than half the size of ours.

About 1.8 million years ago, they were the first humans to know winter.

Ongoing excavations at Dmanisi, a site in the Republic of Georgia, have yielded scores of early hominid fossils, including five skulls and, most recently, a complete male pelvis found in 2014. The fossils' mix of primitive and more evolved characteristics — such as small brains but body proportions similar to our own — defies how we currently classify our distant ancestors and relatives. An equally compelling mystery, however, is what the hominids were doing at Dmanisi in the first place.

Dmanisi's hominid fossils, the oldest outside Africa, have been excavated with more than 10,000 bones from about 50 other extinct species, including deer, bears and saber-toothed tigers. The trove of fossils hints at the rich biodiversity of the site, which is hundreds of miles north — and more than a thousand miles away — from any other hominid activity during the Gelasian Pleistocene, 1.8 million to 2.5 million years ago. Hominids, specifically the fairly advanced *Homo erectus*, began to disperse from Africa only at the tail end of that period, according to the current timeline of human evolution.

Perhaps it's time to rewrite that chronology.

Beautifully preserved for about 1.8 million years, the Dmanisi fossil known as Skull 5 (left) has a small, primitive braincase — less than half the volume of our own. But the hominids' bodies were similar to modern humans, as shown reconstructed by artist Elisabeth Daynes (right).

THE KILLING GROUNDS

"Dmanisi was a good place to die," says Martha Tappen, a paleoanthropologist at the University of Minnesota and part of the Dmanisi team since 2001. She believes the site's natural features made it an attractive place for numerous species — and for the large carnivores that hunted them.

Dmanisi sits atop a promontory overlooking the confluence of two rivers. Access to water likely lured the animals to the area initially. Once they moved up the wedge-shaped bluff, however, they had nowhere to run to escape the resident megacarnivores, including the lion-size European jaguar, *Panthera gombaszoegensis*.

Tappen, who describes her role on the team as largely "trying to determine who ate whom," has found a lack of weathering on Dmanisi's animal and hominid bones, suggesting they were sheltered from the elements soon after death. About a fifth of the bones have signs of carnivore predation, and many fossils were found as segments of articulated skeletons — think an entire shoulder rather than just a collarbone. Some of the fossils were deposited with ligaments still attached. The evidence suggests that many of the bones were piled in dens of the large carnivores.

The beautifully preserved Skull 5, for example, described in *Science* in 2013 and arguably the most famous Dmanisi hominid fossil, was found beside a deer bone and a baby rhinoceros femur that had been chewed.

Tappen also found evidence, however, that the hominids were predator as well as prey. The deer bone beside Skull 5, for example, had a stone flake tool

The unmistakable remains of an early species of saber-toothed cat, found at Dmanisi with more than 10,000 other bones.

embedded in it, and tool marks on some of the other animal bones suggest the hominids, at least occasionally, enjoyed the choicest cuts.

"We see evidence the hominids were eating meat from around the femur and humerus. That, along with the torso, is where carnivores eat first," says Tappen.

The hominids may have used rounded stones found around the site to throw at predators, either in defense or to scare them away to scavenge their kills, Tappen believes. If proven, the stones would be one of the earliest documented weapons wielded by *Homo*.

A key finding at Dmanisi, says Tappen, is that all of Dmanisi's herbivores, and most of its carnivores, were from Eurasia, not Africa.

"In terms of hominids spreading out of Africa, it seems that they did not spread with other fauna. That they made it to the higher latitudes without other animals moving at the same time tells you humans made it out of Africa not because the environment was changing or because the biome was moving," says Tappen. "They went of their own volition."

The Dmanisi site, tucked into the Anti-Caucasus mountains at about 41 degrees north latitude — similar to present-day New York and Beijing — would have presented a particular challenge for an African species.

"At the higher latitudes, you're confronting seasonality for the first time," Tappen says. "They were experiencing winter. No other primate lives where there's no fruit in winter.

The Dmanisi site overlooks the confluence of two rivers and includes a ruined medieval town and fortress.

There may be a dry season, but there's not a cold winter like these individuals in Dmanisi were experiencing."

Tappen believes the hominids, whose brains she describes as "the size of a bocce ball," survived by adapting to a more meat-centric diet and by eating things like tree bark.

But what puzzles some researchers even more about the Dmanisi hominids showing up more than a thousand miles north of Africa, much earlier in the fossil record than expected, is that they made it to the mountain valley without any advanced technology.

OUT OF AFRICA EARLY

"It would seem that, in the earliest dispersal of humans, some kind of technology would give you an edge. If you don't have hand axes, maybe you have fire," says Michael Chazan, an archaeologist at the University of Toronto. "But there is no evidence of either at Dmanisi."

Chazan is not part of the Dmanisi team, but he has reviewed evidence

NORTHWARD BOUND
Early hominid sites tell us *Homo* evolved in eastern Africa and moved into Eurasia. But when?

of the technologies used by hominids there. He says few stone tools have been found at the site compared with other early hominid occupations, such as Ubeidiya in Israel. Intriguingly, the tools at Dmanisi were Oldowan style, also known as flake and core: It's the simplest stone tool technology, first seen in Africa 2.5 million years ago. In contrast, hominids living in Africa at about the same time as the Dmanisi population were making much more advanced tools, such as hand axes.

The finds at Dmanisi hint that the first humans to leave Africa were not the larger-brained, hand ax-toting, potentially fire-wielding *H. erectus*. Rather, they were a much more primitive hominid population, possibly *Homo habilis*, whose members lived in, or at least transited, Dmanisi much earlier than what our accepted chronology of human evolution

OPPOSITE: GURAM BUMBIASHVILI/GEORGIAN NATIONAL MUSEUM; S. ENTRESSANGLE/E. DAYNES/SCIENCE PHOTO LIBRARY; THIS PAGE: PHOTOS BY KENNETH GARRETT/NATIONAL GEOGRAPHIC CREATIVE; MAP BY JAY SMITH

indicates. It's possible that the current view on when humans first left Africa is wrong, but if those first pioneers traveled without the easily recognizable advanced tools of *H. erectus*, it's also possible we may never find proof.

Says Chazan: "The problem that keeps you awake, if you think about these things, is that if there was a dispersal event 2 million years ago, before *H. erectus*, would we see it? If they were using stone tools made of local materials, would we even pick it up? Are we building our models based on things we can't see?"

Dmanisi team member Tappen agrees the site's fossils are challenging our current understanding of human evolution — but she's not losing sleep over it.

"As archaeologists, we go with what we have. We make hypotheses and try to test them, and then you dig up something new and go 'oops.' And you have to make up a new hypothesis," says Tappen.

"The Dmanisi individuals are not too different from *H. habilis*. We should find them dispersing out of Africa 2.5 million years ago," she explains. "We don't have that evidence yet, but we have to expect it's out there."

If there were an earlier hominid exodus from Africa 2 million years ago or longer, researchers don't expect to find the proof at Dmanisi. All the hominid fossils found so far have been between two layers of volcanic rock from regional eruptions conclusively dated between 1.76 million and 1.85 million years ago.

REWRITING THE FAMILY TREE

Archaeologists began digging at Dmanisi in the 1930s, interested in the site's ruined medieval fortress. While excavating the fortress cellars in the 1980s, researchers began finding the teeth and bones of extinct animals from the early Pleistocene — the first clue to the site's prehistoric significance.

The significant variation among five hominid skulls from Dmanisi, as shown in this computer-drawn rendering, has led some experts to argue the skulls represent more than one species from the genus *Homo*.

"If you try to explain what the site means, you can't," says archaeologist Michael Chazan. "What excites people is not the answers. It's the questions. Dmanisi is that kind of story."

Since the first hominid fossil was found in 1991, however, the uniqueness of the site itself has been overshadowed by the strange appearance of its early humans. Their short stature and small braincase suggest *H. habilis*, which first appeared about 2.3 million years ago in Africa. But *H. habilis* never left Africa, according to the current fossil record. And other characteristics of the Dmanisi hominids, such as their more modern limb-to-body proportions, don't match up with *H. habilis* at all but do fit with *H. erectus*, which evolved in Africa about 1.9 million years ago. *H. erectus* eventually spread as far as China and Indonesia, but not until much later in the fossil record than the Dmanisi finds.

Dmanisi team members, among others, contend that the Georgian fossils belong to a single early population of *H. erectus* or to a single sub-subspecies, *Homo erectus ergaster georgicus*. An opposing camp insists the fossils represent multiple species of as-yet-unnamed hominids.

"In the 1990s, on the family tree of hominids, we had maybe 12 species. Now there are 25," says Ian Tattersall, a paleoanthropologist and influential author of books such as *Becoming Human*. "The family tree is even more bushy than that, but people are still trying to fit things into pre-existing categories."

Tattersall is not part of the Dmanisi team, but he has examined some of the fossils. In 2014 he co-authored an article in *Science* criticizing the idea that the hominids all fell under the *H. erectus* umbrella. He believes the five skulls represent at least two other early hominid species. Differences in age and sex, says Tattersall, cannot account for the wide variation in features such as jaw and brow shape not only among Dmanisi skulls, but also when compared with *H. erectus* fossils from other sites.

"One species may show variation on a theme, but Dmanisi shows a variation *of* themes," says Tattersall.

For now, the fossils' place on our family tree, like their presence at Dmanisi as early as 1.85 million years ago, remains an evolutionary enigma.

"If I had a word for Dmanisi, [that word] would be *tantalizing*," says Chazan. "If you try to explain what the site means, you can't. But what excites people about archaeology is not the answers. It's the questions, the things we don't know. Dmanisi is that kind of story." D

***Gemma Tarlach** is senior associate editor at* Discover.

MARCIA PONCE DE LEÓN/CHRISTOPH ZOLLIKOFER/UNIVERSITY OF ZURICH

Divided Loyalties

What happens when our allegiances conflict?

BY **MICHELLE NIJHUIS**

Last spring, my young daughter and I went to the opening day of Little League season in our small town of White Salmon, Wash. As always, it was a day for classic Americana: The Boy Scouts raised the Stars and Stripes over the ballfield, we sang "The Star-Spangled Banner" and a local celebrity threw the first pitch.

This year, the ceremonial pitcher was Vic Wild, a White Salmon native who won two gold medals in snowboarding at the 2014 Winter Olympics in Sochi, Russia. When the announcer called his name, Wild, wearing dark sunglasses and a flannel shirt, jogged to the pitcher's mound. He grinned and shrugged at the audience, then wound up and let loose a pretty good pitch. The crowd went crazy.

What nobody mentioned — not the announcer, not the players, not the smiling parents — was that Wild, who graduated from the local high school and trained on nearby Mount Hood, didn't win his double gold for Team USA. He won it for Russia, and photos of him with Vladimir Putin prove it.

Our town's celebration of a Russian champion got me thinking about loyalty — which, as it turns out, is a highly complicated emotion. While we generally think of loyalty as a virtue, loyalty to Nazism or terrorism is, of course, anything but virtuous.

Vic Wild, with hometown fans in Washington (above), won two gold medals for Russia (top).

Loyalty, as it turns out, is a highly complicated emotion. Almost by definition, it sets us against one another.

Loyalty, almost by definition, also sets us against one another; loyalty to my family means I'm less concerned about yours. Perhaps most troubling, our loyalties can easily put us at odds with ourselves. "Loyalty may be a single virtue," philosopher Troy Jollimore writes in his book *On Loyalty*, "but because we have multiple loyalties, it tends to attach us to a plurality of values, some of which may conflict with others."

CIRCULAR VIEW

So how do we resolve the internal and external conflicts that loyalty creates? University of Southern California psychology professor Jesse Graham suggests that loyalties surround us like concentric circles, and those circles pull us both outward and inward — outward because we believe we should care for as many people and things as possible, and inward because we believe we should care about our children more than, say, houseflies.

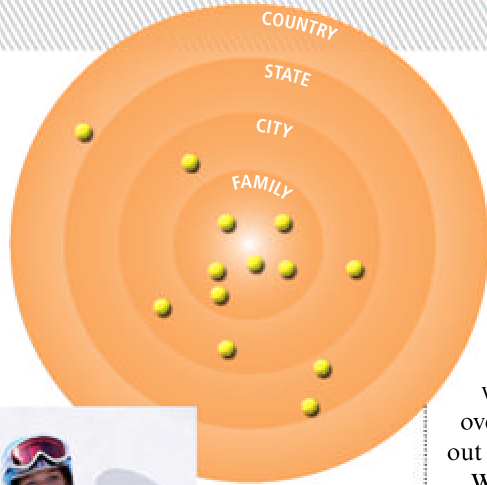
"Is it prejudice or is it good that we have more care at the center of our moral circle?" he asks. "We're pulled in both directions."

Graham, along with Northwestern University psychologist Adam Waytz, recently conducted an experiment in which participants were shown a series of concentric circles labeled with 16 types of loyalties. Graham and Waytz placed immediate family in the middle, and friends, acquaintances, nation, humans and mammals in progressively larger circles. (They labeled the outermost circle with the least loyalty-inspiring entity they could think of: space rocks.)

Graham and Waytz then gave participants a limited number of tokens, instructing them to distribute the tokens among the circles according to their loyalties. They found that all participants assigned more tokens to smaller circles and fewer tokens to larger circles. In other words, everyone's loyalties weakened as the entities became more distant and abstract.

Participants who had expressed conservative political values tended to cluster their tokens more tightly,

TOP: SHAMUKOV RUSLAN/ITAR-TASS PHOTO/CORBIS. BOTTOM: SVERRE BAKKE/WHITE SALMON ENTERPRISE



putting most of them in the smallest circles. Those with liberal political values tended to spread their loyalties thinner, placing at least a few tokens in more distant circles. When Graham and Waytz gave participants an unlimited number of tokens and the same instructions, the results were similar.

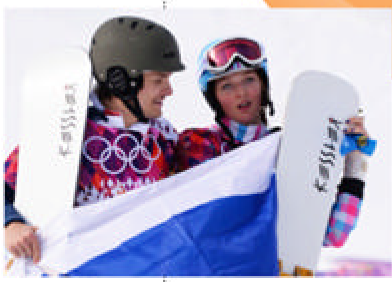
Graham and Waytz's findings suggest that liberal-leaning people may have had less trouble resolving their conflicting loyalties to Vic Wild and Team USA. Since their loyalties tend to extend beyond their national borders to other countries, other species and even other planets, they probably didn't find it too difficult to cheer for a neighbor who also happened to be a Russian champion.

Conservatives, on the other hand, probably struggled more. They wanted to be loyal to a neighbor, but a gold medalist representing another country, especially one at odds with the United States, didn't fall within their personal circles of care.

Age and personal experience influence our responses, too. I was intellectually more than ready to root for Wild, but I was instinctively brought up short by the photo of Wild and the Russian president shaking hands. People too young to remember the Cold War likely saw the photo differently.

Regardless of politics, such conflicts are likely more complicated than they used to be. "In the U.S., at least, we no longer get the kind of moral education that decides these things for us," Jollimore told me. We live in a world that's more individualized and more interconnected than it was just a decade ago, and that, for good and ill, muddies our loyalties.

"We're much more cosmopolitan than we used to be — much more likely to know someone from another place," he says. "And when you're faced with a person in the flesh, you can't generalize. You can't say, 'Well, all Russians are bad.' "



People cluster loyalties around family and others close to them (above). Russian Olympian Alena Zavarzina with Wild (left).

COHESIVE RESPONSE

Of course, we residents of White Salmon didn't work out these complexities in isolation. Conflict resolution scholar Daniel Druckman of George Mason University and Macquarie University, who studies how groups react to heretics and renegades, says that while each group member has a set of values to consider, groups will often, over time, come up with a cohesive response to any violation of the norm.

"People don't just think through their reactions individually — they talk about them with one another," he says. "The extent to which they reinforce each other will be what you hear on the street."

When Wild won his medals in February, our local paper trumpeted his victories but buried his Russian citizenship deep in the story. A few days later, though, the paper applauded both Wild and his choice to ride for Russia, writing in an editorial that the U.S. team got exactly what it deserved. (Had the U.S. been able to claim Wild's two golds, Russia, Norway and the U.S. would have tied for first place in the gold-medal count. As it was, the countries placed first, second and fourth, respectively.) On the street in White Salmon, support for Wild was at first somewhat muted. But over time, everyone seemed to work out their internal conflicts.

Wild's personal story helped. He's an alpine snowboard racer, a sport that gets scant money and attention from the U.S. Ski and Snowboard Association. When he started dating Russian snowboarder Alena Zavarzina, who later became his wife, a Russian coach suggested he join Team Russia — and enjoy more funding and support. So many in White Salmon appreciated that he switched teams not for political reasons, but out of a more straightforward desire to reach the top of his sport. The romantics among us liked that he did it for love, too. Gradually, through individual reflection and conversation, we found our collective way toward supporting the local guy: Celebratory banners went up, and a brewery announced a party in honor of both Wild and Zavarzina.

For the members of White Salmon Little League, though, the choices were far simpler. Here was a guy who once played on their field and had grown up to travel the world and bring home two Olympic gold medals. What could be cooler than that?

When Wild returned to the sidelines after his ceremonial first pitch, he was mobbed by players, all waving ball caps and visors for him to autograph. Smiling, he pulled out a pen. As I stood at the edge of the crowd with my daughter, the Cold War seemed very far away indeed. D

Michelle Nijhuis *writes about science and conservation from White Salmon, Wash. A version of this story first appeared in the* Last Word on Nothing *science blog.*

PHOTO: LARS BARON/GETTY IMAGES. ILLUSTRATION: DAN BISHOP/DISCOVER

No Such Thing as a Black Hole?

New theories question just about everything we thought we knew about nature's bottomless pits.

BY **COREY S. POWELL**

The black hole from *Interstellar* is based on current theory, but that theory may not match reality.

DOUBLE NEGATIVE/PARAMOUNT/WARNER BROTHERS

It takes a special kind of personality to argue passionately about the nature of objects that are hundreds of trillions of miles away, impossible to see and impossible even to describe using the known laws of physics. And yet, in the woolly world of modern astrophysics, such personalities are not in short supply. Lately they've engaged in a full-on debate about the nature of black holes, with some of the most fundamental notions about these strange objects suddenly under attack.

Despite what you saw in the movie *Interstellar*, black holes may not be black, and they may not be holes, either. Some theorists argue that the event horizon of a black hole — the boundary where light, matter and Matthew McConaughey vanish from our universe — is actually a brilliant, blistering inferno. Others propose that black holes are more properly described as "gray holes" with fuzzy, leaky outer boundaries. And a few agitators argue that the whole debate is off track because nature makes it impossible for black holes to form in the first place.

All of which might seem like so much theoretical navel-gazing, except that the debate over black holes is a proxy in a much grander battle. Right now, physics is split in two: Quantum mechanics describes small, fast phenomena while general relativity describes large, slow ones.

The debate over black holes is a proxy in a much grander battle: to discern the long-sought theory of everything.

But in the extreme conditions around a black hole, time and space get so stretched that the two theories are forced to overlap. Making sense of what happens at that intersection is crucial for developing a "theory of everything"— a unified set of physical laws that describe the entire cosmos, from the Big Bang to a Big Mac.

FIRE IN THE HOLE!

The trouble began, like so many confounding concepts in modern physics, in the brain of Stephen Hawking. Four decades ago, he realized that a black hole's event horizon is inherently leaky; quantum processes allow a slow but steady flow of particles away from the black hole, a process now known as Hawking radiation. Given enough time, a black hole can evaporate completely. The idea of matter escaping the alleged point-of-no-return was surprising (it's a central plot point in that other recent movie about black holes, the biographical *The Theory of Everything*), but the fate of information that falls into the black hole was what really troubled Hawking's colleagues.

In the current view, which Hawking helped formulate, every event in the universe contains quantum information. When objects fall into a black hole, they take their information with them. That's fine so long as the information stays in there, but if the black hole evaporates, things go all wonky. Coherent information goes in, but what comes out is just noise — Hawking radiation is 100 percent content-free.

Falling into a black hole seems to destroy a slice of reality, which just makes no sense. Hawking and other theorists began searching desperately for ways to prevent information from getting into the black hole in the first place, for ways to let it back out, or even for ways to make peace with the possibility that some information really can be lost forever.

In 2012, Joseph Polchinski of the University of California, Santa Barbara, offered a novel solution: As soon as an object gets pulled across the event horizon, it hits a firewall — an inferno so intense that it erases all the quantum information that object contained. No information gets lost because no information actually makes it through to the black hole's interior. Polchinski pictures the event horizon as a kind of quantum eraser that neatly makes the information paradox go away.

If you think that sounds like a dodgy answer, rest assured that many of Polchinski's colleagues (and even Polchinski himself) thought so, too — though perhaps not for the reasons you'd expect. The problem is that the rules of general relativity mandate physical continuity everywhere in the universe, even around a black hole. There should be no gap in the experience of, say, a doomed astronaut falling across the event horizon.

Or think of it this way: In relativity, the laws of physics look the same from all perspectives. The astronaut may get squished and stretched on the way in, but should still observe physics operating normally. The firewall, on the other hand, is about as abnormal and discontinuous as it gets. Now we've got a new paradox to deal with.

There should be no gap in the experience of, say, a doomed astronaut falling across the event horizon. The astronaut may get squished and stretched on the way in, but should still observe physics operating normally.

At this point, the story circles back to Hawking, who decided there must be a better way out. In a short paper presented last year, he suggests that the event horizon is not a defined boundary at all, but rather a zone of chaos where space and time are completely scrambled. No specific physical event occurs there — no Polchinski firewall — but any information passing through is rendered completely meaningless. Although Hawking dispenses with the traditional idea of the event horizon, he doesn't dispute that black holes exist (as some breathless news stories claimed). Rather, he proposes that black holes are more like gray holes, defined by fuzzy edges that shed energy and garbled information.

As material (dust in this illustration) falls toward a black hole, it heats up and emits radiation. No one knows what happens next.

Even Stephen Hawking can't quite explain how black holes actually work in our universe.

My brain was starting to hurt, so I called on Juan Maldacena of the Institute for Advanced Study, a leading black hole theorist and a neutral third party. He doesn't think much of the firewall concept because it fails miserably at the key task of reconciling quantum mechanics and relativity. "It's telling us how *not* to do it," he says. Does he like the Hawking approach, then? "No. He did not propose anything concrete," Maldacena replies tersely.

When you are trying to solve the riddle of the black hole, nobody gets special treatment, not even Stephen Hawking.

EVENT HORIZON DENIALISTS

Here is where the deniers come in: If black holes keep sprouting paradoxes, the thinking goes, maybe the problem lies with our understanding of the black hole itself. I first encountered black hole denialism during a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cosmology conversation with Laura Mersini-Houghton of the University of North Carolina, who mentioned, as a casual aside, "Oh, I also proved black holes don't exist." Over the past year, she has written two papers (one published, one in press) laying down the gauntlet.

Mersini-Houghton is flipping around Hawking's old ideas. He considered the radiation released by black holes after they form. She looks instead at the radiation generated by a massive, collapsing object before it ever crosses the event horizon. In Mersini-Houghton's analysis, the resulting energy and opposing pressure become so intense that it stops the infall, reverses it, and flings everything outward. The result is "fireworks, not firewalls," as she puts it.

Event horizons, and the paradoxes that go with them, do not exist because the laws of physics guarantee that imploding stars self-destruct before they can become black holes. Cenalo Vaz, a physicist at the University of Cincinnati, recently came to similar conclusions by looking at outward pressure exerted by the structure of space around a collapsing object.

If black holes don't exist, I ask Mersini-Houghton, what are those things at the hearts of most galaxies? Astronomers have found clear evidence of tiny but supermassive objects there, pulling on stars and stirring up hot disks of gas. Her answer cuts to the heart of one of the weirdest aspects of a black hole. As matter moves closer to the event horizon, time slows down from the perspective of an outside observer — that is, from the perspective of us and everyone else on the outside. At the horizon itself, time appears to us to come to a dead halt.

Even if matter never quite reaches the horizon, as in Mersini-Houghton's theory, time could be stretched so drastically that a sudden rebound or explosion (from the collapsing object's perspective) might look like a single, motionless moment (from ours).

Laura Mersini-Houghton thinks the laws of physics prevent black holes' forming.

DAN SEARS/THE UNIVERSITY OF NORTH CAROLINA AT CHAPEL HILL

Put plainly: *To a human observer, black holes do not exist because we can never see them form.* In the traditional view, a star keeps collapsing past the event horizon down to a dot known as a singularity. In the dissenting view, the star collapses to the edge of the event horizon and then hovers there, or rebounds and explodes. But from our outside perspective, there is essentially no difference. All we see is a frozen frame when the star is infinitesimally close to the event horizon. An astronaut falling toward the star would know the answer instantly, but any message that he or she sent would take a near-infinite amount of time to reach us. Nevertheless, because such an experience is possible, there must be a theory to describe it.

Maldacena, like most mainstream physicists, dismisses black hole denialism. The real way to make sense of all this black hole madness, he insists, is to address the underlying clashes between relativity and quantum physics. "A full theory of quantum gravity must resolve them," he emphasizes. And that is, perhaps, the ultimate paradox of black holes: They embody our very deepest scientific understanding of how the universe works, and yet in many ways we do not understand them at all. D

Corey S. Powell**, editor at large of* Discover, *also writes the magazine's Out There blog. Follow him on Twitter,* ***@coreyspowell

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20 Things You Didn't Know About ...

Dust

BY **ELIZABETH PRESTON**

***Dermatophagoides pteronyssinus*, the dust mite.**

1 Dust is universal: It's dry, powdery soil or any other material made up of tiny particles, whether that's in a pile under your bed or the plume of a volcano. **2** Many mammals and birds take dust baths as part of their grooming routines or social rituals. **3** Chickens dust-bathe so devotedly that caged hens sometimes act out "sham" baths on the floors of their cages, without any dust. **4** Humans, on the other hand, go to great lengths to keep dust away. One of the first motorized vacuum cleaners, patented by English engineer Hubert Cecil Booth in 1901, was nicknamed "Puffing Billy" after a famous steam locomotive. Huge, horse-drawn and powered by gasoline, it had to be parked outside, and its hoses were deployed through doors and windows to clean establishments such as Westminster Abbey. **5** And no wonder we try so hard. When Dutch naturalist Antonie van Leeuwenhoek peered at items from his household through the microscope lens he invented, he found tiny spider-like animals — mites — living everywhere. **6** A 2013 study found that household dust mites evolved from parasites that lived permanently on their hosts. **7** The mites feed mainly on dead skin we shed, while both their decomposing bodies and fecal pellets may trigger allergic reactions in humans. **8** Allergies and asthma are only the start of how dust can harm humans. Miners are at risk of silicosis, pneumoconiosis (black lung) and other diseases from coal dust. Breathing asbestos dust can lead to the cancer mesothelioma. **9** Many materials produce combustible dust that's a serious industrial hazard. A 2008 sugar dust explosion in a Georgia factory killed 14 workers. **10** Dust pneumonia killed thousands during the Dust Bowl in the 1930s. A recent study found that 1934 brought the most severe North American drought in a millennium. An unlucky atmospheric circulation pattern may have been made worse by poor farming practices. **11** Dust storms and dust-bearing winds go by many names, including the *haboob* in Sudan to the North African *khamsin* and the Arabian *simoom*. **12** The Bodélé Depression, an enormous ancient lakebed in the southern Sahara desert, is the greatest single source of dust in the world. **13** Dust from Bodélé blows across the Atlantic Ocean to South America, where the iron and phosphorus it contains fertilize the nutrient-poor soil of the Amazon rainforest. **14** The route from Chad to the Amazon isn't the only dust superhighway. Dust from the Gobi desert and pollution from China blow east toward the central Pacific, for example. Particles usually stay suspended in the atmosphere for only four to seven days, but in that time they may travel thousands of kilometers. **15** In Colorado, dust travels from the Colorado Plateau and the Great Basin east onto snow-covered mountains. Dusty snow can't reflect as much sun, so it melts faster, which actually decreases water supply in the region. **16** NASA and a worldwide group of partners monitor the movement of all these particles using a network of robotic sensors. **17** Astronomers also keep track of cosmic dust, tiny mineral grains that obscure the views of our optical telescopes. Cosmic dust is the raw material for new stars and planets, but it sometimes falls to Earth, too. **18** A NASA mission called Stardust launched in 1999 to capture some of this dust. To collect speeding particles without damaging them, the spacecraft carried aerogel, a spongy, silicon-based material that's 99.8 percent empty space. **19** Researchers posted microscopic scans of the aerogel online and enlisted citizen scientists to help search for cone-shaped cosmic dust tracks. In 2014, they announced the result: seven likely particles of interstellar dust. Careful with those. **20** You can observe the effect of cosmic dust yourself in the zodiacal light, a glow visible from Earth that comes from particles scattering sunlight. Visible in the western sky after sunset and in the east before dawn, the light may resemble a city just beyond the horizon — but is really the glow of a perpetually dusty universe. D

A dust storm sweeps through southern Madagascar during a drought.

Elizabeth Preston** writes the blog Inkfish at **DiscoverMagazine.com

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